NAVAL PROFESSIONAL PAPERS

No. 14.

EXPERIMENTS WITH STEEL

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PAPERS AND DISCUSSIONS

ON

EXPERIMENTS WITH STEEL.

REPRINTED FROM VARIOUS SOURCES.

BUREAU OF NAVIGATION,
NAVY DEPARTMENT.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1883.

2249 ST——1

NOTE.

The NAVAL PROFESSIONAL PAPERS are a continuation of the series of NAVY SCIENTIFIC PAPERS previously published by the Bureau of Navigation.

2

CONTENTS.

EXPERIMENTS ON STEEL.

[Memorandum for the information of Board of Trade Surveyors.]

REMARKS OF THE ENGINEER SURVEYOR IN CHIEF, AND HIS ASSISTANTS, RESPECTING THE MILD STEEL MANUFACTURED BY THE STEEL COMPANY OF SCOTLAND; ALSO TABULAR RESULTS OF TESTS.

Steel as a material for shipbuilding and boiler-making has for years been used to some extent. Its general introduction has, however, been delayed, owing to the fact that it could not be regarded as invariably reliable, as it frequently occurred that amongst a batch of plates, the greater part of which had been considered satisfactory, a proportion was found not to possess the properties required, and to fail in the shipyard or boiler-yard. It has been argued, and probably with some truth, that in some cases a prejudice was unjustly created against the use of steel owing to its failure under treatment which should never have been applied to it. The mild steel, which is now being introduced, is of a softer and more ductile character, and much better able to bear the manipulation to which it is subjected, still in some respects it requires special care in its treatment.

Steel is mainly distinguished from wrought iron by its property of becoming harder and more brittle when raised to a red heat and cooled suddenly in water. This peculiarity is attributed to the former containing a greater amount of carbon than the latter, in which generally only a trace of it is found. Steel which contains about 1 per cent. of carbon possesses a very high tensile strength; takes a high degree of temper when heated and cooled suddenly in water, but being brittle in character is unsuited for shipbuilding and boiler-making, both on account of its uncertainty in withstanding the necessary operations in the course of manufacture, and also because of the danger of employing a brittle material to withstand the strains to which steam-boilers and the hulls of vessels are continually exposed. In the mild steel under consideration the amount of carbon is very small, and manufacturers consider as a proof of its suitability for the purposes mentioned that it will when heated and cooled suddenly in water bear bending double. The fact of the material, when treated as described, not taking the degree of hardness usual with ordinary steel has led some persons to doubt the advisability of the term "steel" being applied to it, upon the ground that it is only a purer form of iron. The experience which has been gained with it has, however, shown that it differs in many respects from wrought iron, and that the term "mild steel" in the absence of a better, which has not yet been suggested, is perhaps the most suitable which can be used.

Upon the Board of Trade being requested by the Steel Company of Scotland to sanction the steel manufactured by them in the construction of ships, machinery, and boilers passed by the Board's officers, they were requested to undertake such a series of tests as would enable the advisers of the Board of Trade to judge of its suitability for the above purposes, and also its ability to withstand, without undue injury, the manipulation to which it would be exposed.

The company very readily acquiesced in the justness of the request, and forwarded for testing a set of plates $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch thick; they also caused to be constructed a set of experimental boxes of different thicknesses of steel plate to represent the flat surfaces of steam-boilers. These have been burst by hydraulic pressure, and a large amount of valuable information gained respecting the strength of such surfaces when formed of steel plates.

Having visited the works of the Steel Company of Scotland when every facility was given for inspection, it may be interesting if a few particulars are stated respecting them previous to giving the results of the valuable series of experiments which have been made upon steel manufactured there. The company was originated about the year 1872, and at Newton, near Glasgow, extensive works were erected for the manufacture of steel by the Siemens-Martin process. They are provided with machinery and tools of the most recent and improved description for the manufacture of plates, rails, forgings, &c. The melting-shop has been erected to cover over thirty steel-melting furnaces, eighteen of which, with the necessary gas producers, &c., have been started, and are said to be capable of producing about 65,000 tons of steel per annum. The rail-mill driven by compound reversing engines can roll direct from the ingot about 40,000 tons of rail of ordinary sections per annum, and is also adapted to the rolling of heavy angles, T bulbs, beams, &c.

Three plate-mills now at work at Newton, driven by reversing engines, can roll about 25,000 tons of average plates per annum. A 14-inch bar mill is kept at work on light rails, angles, &c., whilst three 8-ton hammers and one 3-ton hammer are employed for forging slabs, billets, &c. A large foundry has been erected for making steel castings, and, in addition to workshops and smithy, another large iron foundry has been erected for repairing purposes, and for casting the rolls and ingot molds required for the works.

I am informed that the company have recently purchased the Blochairn Works, Glasgow, where furnaces are, it is stated, to be constructed equal to the production of 80,000 tons of ingot per annum.

The reheating and annealing furnaces are heated by gas, and the present consumption of coal and dross at the works for gas-making and steam-power is stated to exceed 100,000 tons per annum.

The company prefer, instead of running direct from the blast furnace, to use selected brands of hæmatite-pig-iron, good steel and iron scrap, and pure iron ores, ferro-manganese being added when the charge is being tapped. A charge of ordinary steel takes from seven to nine hours, and the length of the operation gives those in charge a good opportunity for testing the metal during the various stages of manufacture, and tends to insure a uniform make of steel of the desired quality. The company have directed special attention to the production of mild steel for shipbuilding and boiler-making, and have been doing all in their power, by undertaking the extensive series of experiments which will shortly be considered, to show that a suitable and uniformly reliable quality of steel can be made for these purposes. It is stated that in making mild steel for plates the best brands of Bessemer pig-iron are used, and the charge is frequently tested when in the furnace as well as by chemical analysis. When the steel is being run into the molds a small test-ingot is cast, which, besides being tested chemically, is rolled into a plate, pieces of which are tested by bending. The tensile strength and elongation of the steel are also tested in a machine erected at the works for this purpose. If the charge is found right for the particular purpose required, the ingots are marked with the number of the charge and the quality of the steel. The ingots are afterwards hammered into slabs from which the plates are rolled, and to insure against risk of mistakes a test-piece is cut from each plate and angle, and subjected to the bending and tempering test.

The experiments made, and the attention bestowed by the company in endeavoring to arrive at the best possible quality of steel for shipbuilding and boiler-making have resulted in securing a greater amount of confidence amongst shipbuilders and engineers, and this is more especially the case where the steel has been actually used.

Tables 1 to 19 give the results of tests which Mr. Kirkaldy was requested to make, and are exactly as received. In the body of this report some particulars deduced from Mr. Kirkaldy's tables are given, which will, it is hoped, be found of use when considering the subject.

RESPECTING THE EXPERIMENTS MADE TO ASCERTAIN THE ELASTIC AND ULTIMATE STRESSES AND DUCTILITY OF STEEL PLATES MADE BY THE STEEL COMPANY OF SCOTLAND.

Tables 1 and 13 contain the results of testing for tensile strength and elongation forty-eight specimens cut from twelve steel plates, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch thick. Half the number were cut lengthway of the plate and half crossway. The separation of the strips from the plate was in every case done by the planing or slotting machine, and not by the shearing machine, so as to avoid any disturbance of the texture of the material.

The following summary contains mean results taken from Tables 1 and 13:

Thickness of plate.	Mean elastic stress per square inch.		Mean ultimate stress per square inch.		Mean ratio of elastic to ultimate.	
	Lengthway.	Crossway.	Lengthway.	Crossway.	Lengthway.	Crossway.
Inch.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Per cent.*	*Per cent.*
¼	19.0	19.1	31.0	31.4	61	60
½	15.8	15.7	28.9	28.6	54	55
¾	15.8	15.6	29.5	29.1	53	53
1	14.9	14.8	28.0	28.0	53	52
Total mean..	16.3	16.3	29.3	29.2	55	55

The term "ultimate stress" is always understood to mean the stress which being gradually applied will break the specimen; but as there is by no means the same unanimity respecting the meaning to be attached to the term "elastic stress," it may, in order to prevent misunderstanding, be well to quote some remarks made by Mr. Kirkaldy, by whom it is employed. In his published report on the Fagersta steel he gives examples of his method of ascertaining the elastic stress or elastic limit of the material under test. The following table is extracted from one in the above report:

Abstract from table giving detailed results of experiments upon Fagersta steel plate to ascertain the increments of length with corresponding sets under a gradually increased pulling stress.

Description.	Marked.	Test No.	Thickness.	Stress in pounds per square inch. Increments and sets, inch. 10,000.	12,000.	14,000.	16,000.	18,000.	20,000.
Unannealed................................	1. ¼	1,058	.245	{ .027 set }	.034	.041	.048	.056	{ .064 .000
Unannealed................................	1. ⅜	1,062	.380	{ .030 set }	.038	.046	.054	.062	{ .070 .004
Unannealed................................	1. ½	1,066	.500	{ .028 set }	.034	.040	.046	.052	{ .058 .000

Description.	Stress in pounds per square inch. Increments and sets, inch. 22,000.	24,000.	26,000.	28,000.	30,000.	32,000.	34,000.	36,000.	38,000.
Unannealed................................	.072	.079	.086	.094	{ .102 .006 }	.110	.118	.133	.151
Unannealed................................	.078	.086	.104	.204	{ 1.75 1.64 }	2.49	3.07	3.83	4.63
Unannealed................................	.064	.070	.077	.139	{ .648 .500 }	1.92	2.45	3.08	3.61

Abstract from table giving detailed results of experiments, &c.—Continued.

Description.	Stress in pounds per square inch. Increments and sets, inch.						Stress.		Ratio of elastic to ultimate.
	40,000.	42,000.	44,000.	46,000.	48,000.	50,000.	Elastic per sq'r inch.	Ultimate per sq'r inch.	
Unannealed	.428 / .311	1.84	2.70	3.26	4.15	5.34	35,600	54,140	65.7
Unannealed	5.40 / 5.20	6.56	8.05	10.45	14.55	......	25,400	48,925	51.9
Unannealed	4.59 / 4.43	5.55	7.00	8.55	11.00	14.15	27,500	50,160	54.8

He remarks as follows: "Running the eye along the lines it will be noticed that the specimens extend at a comparatively uniform and slightly increasing rate at each addition of 2,000 pounds per square inch to the load, until a certain point is reached, when the rates of extension more or less rapidly increase, which point indicates the elastic strength of the material. A short line is placed under the figures in this table to call attention, at a glance, to where the increments cease to be uniform, and where it is found that the elasticity of the specimen has become impaired."

It will be observed that in some cases a set is recorded at a lower stress than the elastic stress, so that the term as applied in these tables does not mean, as understood by some persons, the stress at which a permanent set takes place.

By the term "elastic stress" is sometimes understood the stress or load which, although not causing fracture at once, will do so if repeated a sufficient number of times. What relation there may be between the above stress and the elastic stress, as recorded in Mr. Kirkaldy's tables, it is impossible to say without further experiments. Although a matter of the deepest interest to engineers and shipbuilders, few, if any, experiments have been made to settle this question as regards iron and steel, a fact much to be regretted, as the information to be obtained would doubtless be most valuable, and possibly lead to great economy in the application of those metals.

Referring to the summary we see that, with the exception of the $\frac{1}{2}$-inch plates, there is a gradual increase in the ultimate stress with the reduction of thickness, the ultimate stress of the $\frac{1}{4}$-inch plates exceeding that of the 1-inch by about 10 per cent. A similar increase occurs with the elastic stress, which, in the case of the $\frac{1}{4}$-inch plates, exceeds that of the 1-inch by about 27 per cent. The increase of the elastic stress with the reduction of thickness is thus more marked than the ultimate. The above remarks are made regarding the lengthway specimens, but the values for the crossway are not very different.

There is also a steady increase in the ratio of the elastic to the ultimate stress as the thickness is reduced, that of the $\frac{1}{4}$-inch plate having a large excess over the others. In the ¼-inch lengthway specimens it exceeds that of the 1-inch by about 15 per cent. The increase in the elastic and ultimate stresses with the reduction of thickness is probably due, to some extent, to the greater amount of working which the material receives in the process of rolling; it is, however, not likely to be wholly due to this cause.

Thickness of plate.	Ultimate extension in 10 inches.		Contraction of area at fracture.	
	Lengthway.	Crossway.	Lengthway.	Crossway.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
¼ inch..............	23.5	21.2	46.0	39.9
½ inch................	29.8	28.9	53.2	40.9
¾ inch................	29.2	26.6	46.8	38.3
1 inch................	30.6	25.6	50.4	42.4
Total mean.........	28.2	25.5	49.1	40.3

The ultimate extensions of the ¼-inch specimens are considerably less than with the thicker plates; this fact, together with the lower contraction of area at fracture, appears to show that they are of a rather harder quality. Even if made from the same charge there is possibly a liability to a greater degree of hardness in the very thin plates owing to their being more rapidly cooled in the process of annealing, unless it is performed under exceptionally favorable conditions.

The ultimate stresses of the ¼, ½, ¾, and 1 inch plates lengthway and crossway are respectively almost equal, and the same also occurs with the elastic stresses. It is worthy of note that, although the mean elastic and ultimate stresses lengthway and crossway are almost identical, the mean contraction of area at fracture, and ultimate extension lengthway, are greater than crossway, showing that the ductility of the material in the former direction is greater than in the latter.

The fact of the mean contraction of area at fracture of the lengthway and crossway specimens being 49.1 and 40.3 per cent., respectively, indicates the possession of great ductility, and in this respect the steel compares most favorably with both iron ship and boiler plates. The following tables give the mean results of testing a number of iron ship plates of various brands, the specimens being cut lengthway and unperforated:

Results of testing ordinary iron ship plates.

Thickness of plates.	Mean ultimate stress per square inch.	Mean contraction of area at fracture.	Mean ultimate extension in 10 inches.
	Tons.	*Per cent.*	*Per cent.*
¼ inch.......	24.00	6.8	7.0
½ inch.......	22.62	4.7	6.7
¾ inch	19.42	4.8	3.6
Total mean .	22.01	5.4	5.7

The results of testing a large number of ordinary iron boiler plates of different brands are as follows, the specimen being unperforated:

Results of testing ordinary iron boiler plates.

Thickness of plates.	Lengthway.			Crossway.		
	Mean ultimate stress per square inch.	Mean contraction of area at fracture.	Mean ultimate extension in 10 inches.	Mean ultimate stress per square inch.	Mean contraction of area at fracture.	Mean ultimate extension in 10 inches.
	Tons.	*Per cent.*	*Per cent.*	*Tons.*	*Per cent.*	*Per cent.*
½ inch	21.20	12.91	9.0	19.03	4.28	2.7
¾ inch	21.40	13.30	10.1	18.67	5.08	3.8
1 inch	20.86	13.0	9.8	17.74	3.87	3.1
Total mean	21.15	13.07	9.6	18.48	4.41	3.2

Comparing these results with those obtained with the ship plates the greater uniformity of the boiler plates of all thicknesses will be remarked. The larger contraction of area at fracture and ultimate extension of the iron boiler plates also indicate the higher degree of ductility which they possess as compared with the iron ship plates.

The following summary contains the mean results of the two last tables, also the results of testing the steel plates, together with the mean results published by Mr. Kirkaldy respecting a number of Yorkshire wrought-iron plates tested by him:

Description.	Thickness of plates.	Lengthway.			Crossway.		
		Mean ultimate stress per square inch.	Mean contraction of area at fracture.	Mean ultimate extension in 10 inches.	Mean ultimate stress per square inch.	Mean contraction of area at fracture.	Mean ultimate extension in 10 inches.
	Inch.	*Tons.*	*Per cent.*	*Per cent.*	*Tons.*	*Per cent.*	*Per cent.*
Iron ship plates	¼, ½, ¾	22.01	5.4	5.7			
Iron boiler plates, ordinary quality.	½, ¾, 1	21.15	13.07	9.6	18.48	4.41	3.2
Yorkshire wrought-iron plates.	⅜, ½, ⅝	21.3	20.6	16.7	20.3	14.7	11.2
Steel plates of Steel Company of Scotland.	¼, ½, ¾, 1	29.3	49.1	28.2	29.2	40.3	25.5

The thicknesses of the plates experimented upon are not identical in the different classes, but the results for the present purpose of comparison are not practically affected thereby. Comparing the steel with the iron the ultimate stress of the former is about 36 per cent. greater than the mean of the latter. The contraction of area at fracture of the steel largely exceeds that of the different irons. In the case of the steel lengthway it is 49.1 per cent. against 20.6 per cent. for the Yorkshire iron, 13.07 per cent. for the ordinary iron boiler plate, and 5.4 per cent. for the iron ship plate. As the contraction of area at fracture is a guide to the ductility of materials, it will at once be understood to how large an extent the ductility of the steel plates exceeds that of the iron, especially the ordinary boiler and ship plates.

Another fact worthy of attention is that whilst in the case of iron plates the ultimate stress and contraction of area at fracture crossway are less than lengthway, rendering it always desirable to apply the principal strains lengthway of the iron plates, this does not appear to apply to so great an extent with the steel tested, for the ultimate stresses in both directions are almost identical and the ductility crossway is not much less than lengthway.

It will have been observed that the mean ultimate stress of some of the common ship plates is greater than that of either of the other descriptions of iron plate. This is by no means uncommon, a high ultimate stress being often found to occur with hard brittle plates. The more ductile plates are, however, preferred even with a lower ultimate stress, because of the brittle plates suffering more from punching and being liable to snap suddenly.

When a brittle material is tested to destruction there is little or no indication of approaching fracture, the specimen breaking suddenly. If, however, this mild steel is watched whilst under pulling stress, it is seen that a considerable extension and reduction of cross section takes place before the greatest stress is reached, thereby proving that the material is increased in strength by the process of drawing out, just as steel and some other kinds of wire are found to be stronger than the material from which drawn.

The degree of ductility this steel has been shown to possess is a quality which renders it very suitable for use in shipbuilding and boiler work. It is indeed difficult to overestimate its importance, as unless injured in the ship-yard or boiler-yard, the material is thereby endowed with a great safeguard against sudden failure. In the event of overstraining of either a ship or boiler, instead of sudden failure occurring, as would be the case if made of a brittle material, warning of danger would be given by leakage at the riveted joints, owing to the reduction of section of the plate between the rivet holes, and the consequent elongation of the rivet holes. The extent to which this occurs will be considered further on when dealing with the perforated specimens.

It has been remarked in some quarters that the great ductility of soft steel is a disadvantage. This opinion would appear to have been expressed owing to a belief that its elastic stress is so low as to give the material very little advantage over iron for sustaining loads. This, however, is evidently erroneous; the results of the experiments under consideration show that the elastic stresses of the steel lengthway and crossway are about 55 per cent. of the ultimate. We find by referring to the published reports of Mr. Kirkaldy, respecting the Essen and Yorkshire wrought-iron plates, as follows:

Thickness.	Ratio of elastic to ultimate stress.			
	Essen wrought-iron plates.		Yorkshire wrought-iron plates.	
	Lengthway.	Crossway.	Lengthway.	Crossway.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
⅜ inch.......	54.2	56.0	58.5	62.4
½ inch.......	48.9	50.2	58.8	62.3
⅝ inch.......	51.0	51.6	58.1	59.6
Mean.....	51.3	52.6	58.4	61.4

So that in the steel plates in question the ratio of the elastic to the ultimate stress, viz, about 55 per cent., stands about midway between that of the above two high-class irons, although the ductility of the steel is in excess of that of the Essen plates, and more so of the Yorkshire plates.

Summarizing the last three columns in Tables 1 and 13 respecting the lengthway specimens we get as follows:

Thickness of plates.	Mean extension set in 10 inches.		
	At 50,000 lbs. per square inch.	At 60,000 lbs. per square inch.	Ultimate.
	Per cent.	*Per cent.*	*Per cent.*
¼ inch.......	1.50	6.36	23.5
½ inch	4.80	10.9	29.8
¾ inch.......	4.99	9.62	29.2
1 inch.......	5.73	13.25	30.6
Mean.....	4.25	10.03	28.2

Owing to the lower ultimate stress of the Yorkshire plates we are unable to compare the extension sets with those of the steel plates at stresses of 50,000 pounds and 60,000 pounds per square inch. At 30,000 and 40,000 pounds per square inch the mean extension sets of the ⅜, ½, and ⅝ inch Yorkshire plates are respectively 0.65 and 5.43 per cent. The above stresses are respectively 62 and 83 per cent. of the mean ultimate stress. Tables 1 and 13 do not contain the extension sets of the steel plates at these particular stresses. Mr. Kirkaldy was written to respecting the extension set at the latter, but stated that it was not ascertained. Fortunately we have the means of comparison in the case of the specimens prepared by Mr. Halket from steel plates supplied by the Steel Company of Scotland, and which will be referred to in the next section. From the results obtained by testing them, it was found that at 62 and 83 per cent. of the ultimate stress the mean extension sets in 10 inches were respectively 0.47 and 5.9 per cent., the extension sets for the Yorkshire wrought-iron plates at the same proportion of the ultimate stress being as stated above 0.65 and 5.43 per cent. respectively. We thus see that although the *ultimate* extension set of the steel largely exceeds that of the Yorkshire iron plates, the extension set of the former at 62 per cent. of the ultimate is only about three-fourths of that with the latter, but at 83 per cent. of the ultimate is slightly greater.

Probably few practical engineers or shipbuilders could be found who would seriously assert that the above high-class iron plates are unsuitable for employment in the construction of ships, as well as boilers, if considerations of expense did not prevent their general use. As the extension set of the steel compares so favorably with that of high-class iron plates at the same proportion of the ultimate stress, its suitability for shipbuilding and boiler-making is thus amply proved by the experiments, so far as ductility is concerned.

Continuing the examination of the summary, we find that whilst at the mean *ultimate* stress of 65,632 pounds per square inch there is an ultimate extension of 28.2 per cent., yet at a slightly lower stress of 60,000 pounds or about 90 per cent. of the ultimate the extension set is only about one-third of the ultimate extension. The remainder thus takes place during the application of the last 10 per cent. of the ultimate stress. It should not be forgotton, as has been pointed out by Mr. Kirkaldy in his published works, that ultimate extension consists of two parts, (1) general stretching, and (2) stretching near the point of fracture which is due to contraction of area. It is evident that, as with other soft metals, the ultimate extension of mild steel consists largely of the latter.

CORROSIVE EFFECTS OF STEEL ON IRON IN SALT WATER.

By J. Farquharson, Esq.

[Read at the twenty-third session of the Institution of Naval Architects, 30th March, 1882; the Right Hon. the Earl of Ravensworth, president, in the chair.]

At the meeting of this Institution last year attention was drawn to this subject, and some particulars furnished of actual cases of rapid corrosion. The facts then stated were rather suggestive than conclusive that its origin was the steel combination, as there are other known causes of equally rapid corrosion where no steel is present. Large iron forgings, besides being liable to external influences, contain within themselves elements of decay as rapid as any then noticed. Such forgings are made up of numerous smaller ones, and after being welded up into one whole they contain more or less magnetic oxide, which is as destructive as a like quantity of copper would be if placed in its stead; the well-known fissures, or deep seams, which appear more or less in all rolled or forged iron when corroded by salt water, are wholly due to this cause; these fissures bear in direction a certain relation to one another, by which they are readily known when the actual case is before us, but not otherwise. Although the Admiralty practice does not involve combinations of iron and steel to any great extent, the question raised last year was considered of sufficient importance to test by actual experiment, the results of which I am now permitted to bring before you. Before doing so, in order that the basis of the experiment may be clearly understood, it may be well to notice, briefly, another experiment, made two or three years ago for the purpose of testing the effects of surface oxide, or scale, on rolled mild steel. The two points which that experiment was designed to ascertain were, first, the amount of injury by pitting which the scale might cause in a given time when portions of the surface are unprotected by such scale; secondly, whether such scale action is likely to be permanent. The result went to show that there is practically no diminution at the end of six months' immersion in salt water; steel plates completely covered by scale in combination with a similar steel plate without scale, in some cases did not lose a single grain in weight. Second, the loss of weight or work done by steel oxide was found to be rather more than from a plate of copper of the same size. The experiment now about to be described was therefore undertaken with a full knowledge of these results, which account for much of the confusion and misapprehension which have arisen in cases where scale was neglected, and which show that in any case intended to test relative corrosion of metals surface scale, or oxide, must not be neglected; that care must be taken that the materials used are iron and steel and nothing else, and that the surfaces be large enough to give a good average result. In the present case, plates of iron and steel of equal size, with an aggregate surface of 48 superficial feet, were used. After having the scale completely removed by dilute hydrochloric acid, they were singly weighed, marked, and placed in a grooved wooden frame, parallel and one inch apart, iron and steel alternately. The first, third, and fifth pairs were electrically combined by straps of iron at the tops; the second, fourth, and sixth pairs being left unconnected, and therefore each plate of which was only subject to ordinary corrosion, as if no other metal existed. The whole series so arranged were placed in Portsmouth Harbor, and left undisturbed for six months, when they were taken up and again weighed. The loss of each plate was found to be as under:

		Oz.	Grains.
Steel	combined	0	427
Iron	combined	7	417
Steel		3	340
Iron		3	327
Steel	combined	0	297
Iron	combined	7	77
Steel		4	0
Iron		3	190
Steel	combined	2	337
Iron	combined	6	0
Steel		4	157
Iron		4	57

From the above it will be seen that the three iron plates combined with steel lost 21 ounces 57 grains; that the three similar iron plates not combined lost only 11 ounces 137 grains. The plates were identical in size and all cut from the same sheet, the effect of combination with steel being to nearly double the loss of weight. The proof that the great excess of loss was not due to anything in the plates themselves will be clearly seen by comparing the combined and uncombined steel plates thus: The three combined with iron lost only 4 ounces 187 grains; the three uncombined lost 12 ounces 60 grains, or nearly three times as much as those protected electrically by the iron. These two facts taken together, viz, iron combined with steel invariably lost more, and that steel so combined lost less, prove to a demonstration that electrical action existed. The difference in such loss of weight is a measure of the amount of such action from which it would be easy to draw wrong conclusions. One thing may be inferred, viz, that in this particular case about two-thirds of the electrical energy of the combination was given up in reducing the metal, and the other one-third in the intervening liquid. Taking the distance apart into consideration, it will be seen that the energy was considerable. The laws of electro-chemical action are brief, simple, and invariable, but the results are so modified by conditions which interefere in practice that a clear appreciation of them is necessary in each particular case. It would not be safe to infer that if these plates had only been one-fourth the distance apart, the loss would have followed the well-known law, because in such a case it is probable that the action would soon have been arrested by the formation of rust between the plates; on the other hand, if the iron plates had been protected, except a patch in the middle by waterproof material, all other things remaining the same, it is quite certain that the result would have been serious injury to the plate by pitting of the exposed part on which a very large portion of the energy in such a case would have been concentrated. Again, had the plates been placed edge to edge and contact maintained, the iron would certainly have suffered much on the edge next the steel. Before leaving this part of the subject a word of explanation with reference to a difference which may be noticed in the relative loss of the third pair of combined plates is necessary, in which case the steel lost more and the iron less than in other similar pairs. The probable cause of this is that the connection at the top was less perfect than it should have been, and that in consequence rust formed between the connecting strap and the plate, which after a time arrested the electrical energy and reduced it to a case of simple corrosion. With this exception, which is not a large one, the results are fairly uniform, when judged in the light of local influences which may exist in the individual plates.

The main object of this experiment was to test the effects of combinations of iron and steel, and the lesson taught is to either avoid altogether such combinations or to take care to so modify the conditions as to minimize the injury to the iron; but you will observe that the arrangements in this experiment are such that the results may throw some light on a still more important question, viz, the relative endurance of iron and steel when freed from injurious combinations. The already extensive and still growing use of steel makes this a matter of very great importance. Assuming that the unconnected plates of steel and iron represent the normal loss of each under ordinary and equal conditions, they approximate so closely that the endurance may be considered as practically the same, and this result agrees with that obtained from other and more extensive tests previously made for the Admiralty, and which formed the basis and justification of the use of steel instead of iron in naval construction. In the present experiment the unconnected plates had an aggregate surface of 12 superficial feet each metal. The total loss of weight was—iron, 11 ounces 137 grains; steel, 12 ounces 60 grains; difference in favor of iron on the whole surface 360 grains weight, or 30 grains per foot superficial, which is inconsiderable. A careful examination of the steel plates in this and other cases, after immersion, convinces me that these results (satisfactory as they may be when taken in conjunction with the other advantages of steel) are neither as good as they might be or as they would be if the importance of uniformity were recognized and the ingredients thoroughly mixed as they should be in the process of manufacture. In almost every plate there are evidences of local action between one portion and another—a sure indication that the manganese is not evenly diffused throughout. The plates used in this experiment are here, and we advised all interested to examine them and judge for themselves. In a former case in which the surfaces before immersion had been finished bright by fine filing, the marks could be seen after six months on some parts, whilst other parts of the same plate were well corroded. In the present case the plates were not so prepared, but there are equally clear evidences of the facts observable. I commend this matter to the attention of steel-makers and steel-users, who are both interested. It has been said that manganese is difficult of diffusion, but if its importance as affecting the durability of the steel is recognized, means would soon be found to improve it. Knowing the facts stated above, on a recent visit to steel works I took careful note of the practice, which was as follows: The furnace was tapped, and as soon as the molten steel began to run into the ladle, two men, each with a shovel, began to throw the ferro-manganese into the ladle, and this they continued to do until the steel was all in; no steps whatever were taken to mix by stirring or agitation. In such a process the wonder is that the results are no worse than they are found to be. When the ingredients are thoroughly mixed, there is good reason to believe that the endurance of steel, as regards corrosion, will not only be equal to the best iron but far superior, as it ought to be; and the time may not be far distant when consumers may find a ready means for detecting inequalities which will help to secure attention to this important matter.

DISCUSSION.

Mr. MESHAM. My lord, I thought perhaps it would interest the meeting—I will not detain you long—to show you samples of iron treated by a process whereby this magnetic oxide is produced by artificial means, where a portion of the plate has stood two years in continuous submersion in salt water. I have only to add, that I hope the time will soon come when this process will be largely used for the purpose of protecting steel and iron ship-plates. I have this piece of iron, which is at any one's disposal, and I think you will all admit there is not a particle of rust upon it of any kind.

Captain WATT (of Liverpool). My lord, I have a little experience which points to exactly the reverse of that. The conditions are not exactly the same, because the vessel that I sail in was employed in salt water. The screw was worn away on the leading edge, and was patched with mild steel. We found that the mild steel was eaten away by the cast iron. In that case the steel suffered far more than iron.

Mr. B. MARTELL. My lord, I have only a few words to add, and those are in corroboration of what Captain Watt has said. It only shows the mystery that underlies all these things. I think we are very much indebted to the Admiralty for placing the results of their experiments before us in this way. The question of steel for ship-building purposes is now a question of very great importance, not only to the Admiralty, but to the mercantile marine also, and they are not only looking to the quality of it, and to these mysterious symptoms which are said sometimes to occur, but also to its durability. That is a matter that is occupying the very serious attention of many shipowners at the present time. Any information that can be brought before them in the way of real practical experience of this kind is a matter of great importance. As I said before, we are very much indebted to the Admiralty for placing before the public any experiments they make in this way. I would remark, that in the case of a ship built some little time ago (a steel vessel that was riveted with iron rivets), I had an opportunity of seeing her after she had been running twelve months, and I then found that the steel plates in the immediate proximity of the iron rivets had deteriorated very considerably beyond what the iron rivets had; the rivet points protruding some distance beyond the steel-plates, while the steel around the iron rivets had deteriorated very considerably. I am sorry that the builder of that ship—Mr. Raylton Dixon—is not here; he was here this morning to make some remarks upon that point. That appeared to me to show that this deterioration was not due to mere corrosion, but was probably due to galvanic action, from the rapidity with which it occurred, and from its being in so many places immediately round the rivet points. Although we see the plates placed before us here, and can place implicit reliance on the experiments made by Mr. Farquharson, showing the results to be almost invariably that the iron has suffered most from this action, yet, in the case I have mentioned, the steel had deteriorated more than the iron.

Mr. BARNES. Mr. Martell, would you kindly inform the meeting what the nature of the iron rivets was? Was it Bowling, Lowmoor, or ordinary Staffordshire?

Mr. MARTELL. I wish, as I said before, Mr. Dixon was here, but I have reason to believe that it was Continental iron—I think so—because I know at that time he was importing a large quantity of iron rivets from the Continent.

Mr. BARNES. That is very important.

Mr. W. DENNY. I think the paper Mr. Farquharson has brought before us is one for which we have every reason to be thankful, but it is not one that can be easily discussed offhand, because as Mr. Farquharson has pointed out, there are many matters in it, especially these extraordinary looking lines in the specimens (pointing), which are rather suggestive than capable of solution at this meeting, or perhaps for several meetings to come. There are many points about the corrosion of steel, and also the corrosion of iron by steel, that are really worthy of serious consideration. Mr. Martell has given his experience where iron rivets corroded steel plates. My firm has had an opposite experience.

We built for the Peninsular and Oriental Company their first steel steamer, the *Ravenna*, and I drew the attention of the Institution last year to the fact that, while the whole of the hull of the *Ravenna* was steel and the rivets were steel, the only portions that were iron were the forgings and certain covering plates in the rudder—the plates covering the distances between the pintles, the actual rudder plates being steel. What we found in the case of the *Ravenna* was this, that there was a large corrosion (which you can see for yourselves, because here is a cast of it) at the upper rudder band of the *Ravenna's* rudder-post. That corrosion goes in for nearly $\frac{3}{16}$ of an inch, pitting into the iron rudder-post. There was a further corrosion, although not so serious, in some portions of the iron rudder, and there was some little corrosion also in the iron covering plates of the rudder. There was no corrosion whatever in the steel plates of the rudder, showing that whatever effect was produced affected simply the iron and nothing else. While I do not think we can gather anything very conclusive from this paper, or from the experience Mr. Martell, my own firm, and the Peninsular and Oriental Company have had, with regard to the cause of the actual effects produced, there is one conclusion we can draw from them, that it is a very unsafe thing to put any other metal with steel under water. On that account my firm have adopted the practice, in all our steel steamers, of using only steel rivets and steel forgings. Since we have done that we have not, so far, observed any of these defects. There is another point of importance on the subject of corrosion: I had occasion to examine the bottom of a steel steamer lately, and, among other parts, the inlet where the water was taken in for the condenser. This inlet was covered by a large brass plate with holes in it. When that brass plate was removed we were perfectly astonished at the corrosion which had gone on, and which had eaten down into the steel to the extent of $\frac{3}{16}$, and I examined the other inlets in the same ship, and found similar corrosion. I would therefore call attention to the serious danger not only of bringing together iron and steel in a steel ship, but also of placing brass upon the bottom of a steel ship.

A MEMBER. May I ask, Mr. Denny, whether the rudder bearings were bushed with metal in the case of the *Ravenna?*

Mr. DENNY. I think it was lignum-vitæ.

Mr. W. W. RUNDELL. My lord, I should like to ask a previous speaker a question with regard to the example showing corrosion of the plates instead of the rivets; I should like to ask in what sea the vessel sailed, in what harbor she was lying, and under what circumstances these apparently curious occurrences happened. I am not surprised to hear that two pieces of iron may mutually act on one another electrically, because I remember once having a battery composed entirely of plates of iron cut from the same sheet, and therefore of the same chemical composition, but yet these plates of iron formed a most powerful battery, and for this reason, that the plates in each pair were placed in opposite electrical conditions by being immersed in different fluids with a thin diaphragm between; one was excited by nitric acid, and the other was excited by an alkaline solution. They were thus placed in very different conditions, although they were plates from the same material. If we knew the character of the water in which the vessel in question had been lying it would throw some light on the particular circumstances of the case. I should like to ask if it is known in what sea or harbor that vessel had been lying. The mysterious symptoms would probably disappear if the facts were clearly stated.

Mr. DENNY. With reference to which ship—the question of the corrosion of the iron by the steel?

Mr. RUNDELL. I referred to the case mentioned by Mr. Martell—the vessel built by Mr. Dixon.

Mr. MARTELL. The liquid in which these vessels were was salt water.

Mr. MANUEL. May I ask Mr. Martell if he knows from his own experience the action of the iron rivets used in riveting on the mild steel shell plates of the steamer *Ethel*, built in 1878? It so happened that it was a new departure to construct ships of mild steel in the district where I had the honor to serve as engineer surveyor to Lloyds' Registry, and the rivet boys in heating the steel rivets destroyed them. It was then thought under these circumstances, until we found out the cause of the steel rivets becoming weak and unfit, to substitute iron rivets instead of the steel rivets, and as this vessel is periodically surveyed by Lloyds' Registry, Mr. Martell may be able to tell us now, from the time that steamer has been running in salt water, whether the iron rivets are affected by the steel plates, or the steel plates by the iron rivets. That was in 1878. With regard to Mr. Denny's mention of a steamer belonging to the Peninsular and Oriental Company which had steel plates in the rudder, the frame of which was formed of iron, it will be interesting to know, when that steamer returns, the result of putting in iron rivets instead of steel to keep these plates close again, which Mr. Denny says were the cause of the corrosion of the iron. I shall be able to give at some future time some more information with regard to this. The steel rivets which had become loose in the rudder were replaced by iron rivets. I am not quite of the same opinion, and I do not think that there is any such action as Mr. Denny seems to expect. It is very difficult and a very critical thing in constructing a steel steamer to get everything of steel throughout. I do not think if the steel and the iron are faithfully put together there will be very much to fear from the action of the metals. With regard to the corrosion of steel on screw propellers mentioned by Captain Watt, I have had a little experience, and I have not found that even metal such as brass or Muntz metal when put on steel blades has such a bad action as has been stated. For instance, the steamer *Lombardy* has Vickers' steel blades. I think she is at Messrs. Caird & Co.'s yard at present, but she was built by Messrs. Denny & Co. These steel blades corroded so rapidly—in fifteen months or less—that it was found necessary to do something to protect them, and we sheathed them at ends of blades with brass plates with good results, and these blades have now been running for five or six years, and are intact still. Since that I have used this mild steel of twenty-six tons to the square inch on behalf of the Peninsular and Oriental Company for the construction of some propeller blades on account of its superior strength, but again they were subject to this same corrosive action at blade points by salt water. We found that while we got steel blades to stand as regards strength, they corroded very rapidly in one voyage of three months, and to protect them I covered them with brass sheathing, and we have found this to be a marked success; the blades have not deteriorated further, although sheathing was put on in a hurried manner in dry dock, as close as it could be done by workmen. It stands well, and I believe it will be successful, and that we shall be able to keep on the steel blades without having to renew them by such an expensive method as new ones every eighteen months or two years, which has been the case with some of the steamers in the Liverpool mail service. I think Messrs. Vickers fully agree with what I say. They have seen the blades after they had run two voyages, and are quite pleased with the result of putting brass on to steel to prevent corrosion of steel by salt water.

Mr. W. H. WHITE. My lord, I will say a word in reply to the observations of Mr. Denny. Mr. Denny said, as I understood him, that it was undesirable to have brass under water fittings in ships.

Mr. DENNY. Yes.

Mr. W. H. WHITE. In the admiralty service we always have brass under water fittings, and the bottom plates do not suffer in the way Mr. Denny has experienced, because we fit protectors of some other metal on them, which will suffer from the action of the brass, and leave the skin of the ship intact. Of course the principle of protection may be carried further. I will only add that I think the value of this paper will appear on closer reading, but we have here really a large laboratory experiment rather than an example of common practice. We have not the surface protected by anticorrosive paint at all. It is quite possible the results attained here with bared surfaces are exaggerations, as I think Mr. Farquharson will tell us, as compared with anything we could expect to get in the way of wear in actual practice on the bottoms of ships protected by paints. In the experiments the plates had this bare surface, and were immersed in sea-water and fully exposed.

Mr. FARQUHARSON. My lord, first let me refer to a remark made by Mr. White before I forget it. It is quite true that these experiments were made expressly to put the two metals on an equal footing, and under the worst conditions possible. The object of it was to ascertain what effect steel had on iron, or iron on steel; therefore it was necessary, as it is in all experiments, to carefully provide against any extraneous circumstances that would influence the result. Now, with regard to Captain Watt's observations, I need only say that those circumstances were different, and cannot be judged of from anything you see here or what I have said. Mr. Martell has made some interesting remarks with regard to what occurred around iron rivets. That, again, is a case that I should have very much liked to have seen, because there are many circumstances to be taken into consideration that might modify the results. These results follow, and will follow, all similar arrangements placed as that was, but there are many circumstances, I need hardly tell you, that influence it very much. The formation of an oxide on one metal less exposed to the wash of the water than the other at once changes the direction of the current, and would therefore throw the action on the opposite metal. A remark has been made with regard to an iron battery, which leads me to say that we expect, in all wrought iron, conditions which would produce almost anything that you like, provided that you only let us arrange it in the order that will produce that. I think, sir, I need hardly trouble you with any further remarks on the matter, as I think the facts are not challenged.

The President. I am sure you will allow me to convey, not only our formal thanks to Mr. Farquharson, but also will allow me to point out to you that we are under a special obligation to Mr. Farquharson, because he is not a member of our institution, and he has conducted the experiments with the greatest care. I am sure you will see from his paper, and gather from his remarks likewise, these valuable experiments, which I venture to think are of national importance to all users of steel. Therefore you will allow me to convey a special vote of thanks to Mr. Farquharson for his paper, and for the ability with which he has conducted for the admiralty, and the public in general, these most valuable experiments.

ON THE RELATIVE CORROSION OF IRON AND STEEL.

By Mr. William Parker, *Chief Engineer-Surveyor of Lloyds' Register, London.*

A few weeks ago I had the honor to read a paper before a kindred society—the Institution of Naval Architects—on some peculiarities in the behavior of steel, which had come under my own observation, bearing chiefly upon its qualities of uniformity and ductility. On the present occasion I desire to deal with an entirely different branch of the subject, namely, that relating to the power of steel to withstand corrosion, chiefly in connection with marine boilers and in comparison with iron.

When mild steel was first introduced, a few years ago, two questions were prominently discussed: one was its reliability as a constructive material, the other was its durability so far as corrosion, under different conditions of employment, was concerned. The only experience which had been obtained with steel in these directions, up to that time, was with a different quality of the material to that used in the present day, and it was sufficiently various and contradictory to give rise to much disagreement and no little speculation. This, although it retarded the introduction of mild steel, was in one sense an advantage, for it gave rise to extensive experiments which, while they could not entirely set these questions at rest, at least tended to throw light on the peculiarities of the metal, and hence to lead to its more intelligent manipulation and preservation.

Among the earliest important attempts to deal with the question of corrosion in recent years were the investigations of the late Admiralty Boiler Committee. It is not too much to say that the investigations of that committee were eagerly looked for by all interested in the subject. The results have been for some time before the public, and have given rise to much discussion. On the surface they appeared decidedly unfavorable to steel, and deductions have been made from them which are, to my mind, open to exception. I have therefore thought that a brief analysis of the methods adopted in conducting the experiments would be not only interesting, but that, in view of the prominence accorded to those experiments, it is almost called for at the present time.

It will be seen, on looking into the experiments conducted by this committee, that in most of the vertical tubes in which the plates were experimented upon in boiling water (with or without air) there was a copper plate present, and in many instances the different iron and steel plates were held in position by brass or copper rods, while no precautions had been taken to insulate them. Moreover, all the steel plates had been fixed above the iron ones, and as the temperature was greater in the upper than in the lower parts of the tubes, it might have been expected, other things being equal, that the steel would corrode faster than the iron. Fig. 1 shows one of these tubes with the disks attached.

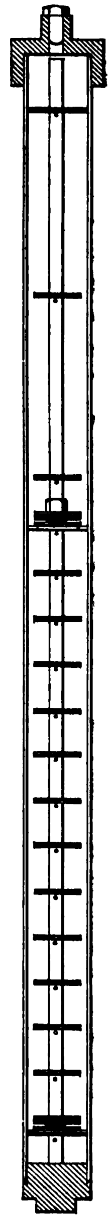


FIG. 1.

It could not be said, therefore, that the results of the investigations of the boiler committee had settled the question of corrosion, and we were induced to look again to the limited experience that existed, and to the comprehensive experiments made about forty years ago by Mr. Robert Mallet for the British Association. These experiments were on chilled and "green-sand" cast irons, made by hot and cold blast, or hammered and rolled cast, blister, shear, and spring steels; hammered and rolled wrought iron, including Swedish, Lowmoor, and many ordinary sorts of iron, down to puddled bars.

The value of Mr. Mallet's paper on these experiments is diminished by the fact that the scale was left on the cast iron in nearly every case, while it is not definitely stated whether it was removed from the wrought iron; but the experiments are nevertheless extremely interesting, and a feature worth notice in them is the appended analyses and densities of some of the materials experimented upon. It may be mentioned that the square plates experimented upon were fixed with their four corners to wooden frames and placed in wooden boxes. The complete results of the experiments will be found in the Transactions of the British Association for the years 1838, 1840, and 1843. The losses by corrosion are given in these tables in grains per square inch, per 732 days, and they can be readily compared with the results of some experiments to be described hereafter, as they are nearly a hundred times greater than if they had been given on the scale I have adopted, which is in pounds per square foot per annum.

Comparing the mean losses given by Mr. Mallet of the ordinary sorts of iron with those of Swedish and Lowmoor iron, a difference in favor of the last two is observed when exposed to river-water and to fresh sea-water, while the latter irons compare unfavorably with the common irons when subject to the atmosphere or to what he calls "foul sea-water." The specific gravity stands in close relation to the amount of corrosion, it being found that in all the different classes of material, whether chilled or "green" cast iron, steel, or wrought iron, the heaviest metal of each description lost less than the lightest one. The analyses, of which a full description is appended to the report, show also beyond doubt that the greater the amount of combined carbon (found by combustion), and perhaps silicon, the less was the corrosion. The manganese, which was present in very small quantities, has played such a subordinate part that its effect cannot be traced. These are, so far as I can gather, the principle conclusions to be drawn from Mr. Mallet's paper, although he was of opinion that the finer the quality of the iron the less it will corrode.

These conclusions, if correct, would be an important addition to our knowledge, but they scarcely accord with the results of experience, and, as I have pointed out, we are at once met by the difficulty that in the case of Mr. Mallet's experiments we are left in doubt whether the scale was removed or not; and in the case of the boiler committee, we are left in doubt how far the want of insulation may have affected the results; and there is the further difficulty in comparing the two sets of experiments, that those of Mr. Mallet were only made in low temperatures and those of the boiler committee in high ones.

It was shortly after the issue of the first report of the boiler committee that I commenced to investigate the subject for the committee of Lloyds' Register of Shipping, and I then endeavored to arrange the series of experiments I am about to describe, so as to avoid as far as possible the sources of error indicated above, and to show the effect of the absence as well as the presence of scale.

In the first place, I obtained twelve disks, $4\frac{1}{2}$ inches diameter and about $\frac{1}{2}$ inch thick, from each of the following manufacturers:

Common iron from the Parkhead Forge Company, Glasgow.
Common iron from Skerne Iron Works Company, Darlington.
Best quality iron from Lowmoor Iron Company.
Best quality iron from Bowling Iron Company.
Best quality iron from Farnley Iron Company.
Best quality iron from Messrs. Taylor Brothers, Leeds.
Best quality iron from Leeds Forge Company.
Mild steel from Landore Steel Company.
Mild steel from Bolton Iron and Steel Company.
Mild steel from Messrs. John Brown & Co.
Mild steel from Steel Company of Scotland.

Six of the disks from each maker were turned bright entirely to remove all scale, and the other six were turned round the edge only, so as to damage the scale as little as possible. Each disk was carefully weighed to $\frac{1}{50000}$th part of its own weight at the Royal Naval College, Greenwich, through the kindness of Professor Reinold. They were divided into six series, each containing twenty-two disks, one black and one bright, from each of the above-named works, and were fixed together, as shown in Fig. 2, by means of an iron rod which had been covered by a glass tube, the plates being separated from each other by means of glass ferrules about $\frac{3}{4}$ inch long and 1 inch diameter, thus, so far as possible, insulating each disk and preventing galvanic action being set up between them. I may mention that one of these sets of disks as insulated was immersed in sea-water, and it was found that by completing the circuit between any two of them a galvanic current was set up, the bright Lowmoor plate being electro positive to the whole of the other plates; and as it is impossible that the energy represented by the galvanic current could be generated without oxidation or corrosion of the metal, the necessity of thoroughly insulating the disks is evident.

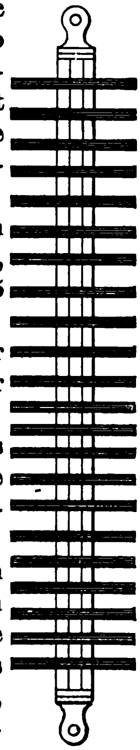


Fig. 2.

One series (A) was suspended on the roof of a building in the city of London, exposed to the action of the atmosphere, from the 13th February, 1879, to 13th May, 1880, or 455 days.

Another set (B) was securly fixed under water to the pier at Brighton from 24th February, 1879, to 7th May, 1880, or 437 days.

A third series (C) was so secured to the engine-room floors of a ship trading to the East as to be freely exposed to the action of the bilge water from 9th June, 1879, to 6th February, 1880, or 240 days.

The remaining three sets (D, E, and F) were hung up in the wide waterspaces between the tubes of marine boilers in such a manner that they could not swing about, and were always about 12 inches below the water-line. These boilers were each in different vessels, employed in different trades, and subjected to entirely different treatment. The vessel containing series D, belonging to the British India Company, was employed in the East Indian trade; zinc was used in these boilers, and they were blown off as seldom as possible. The immersion lasted from the 15th February, 1879, to the 6th June, 1879, and from the 14th June, 1879, to 16th February, 1880, or 361 days.

In the steamer containing set E, owned by the Peninsular and Oriental Company, and engaged in the China trade, no zinc was used in the boilers, which were blown out at each terminal port and run up afresh with salt water. This series was exposed from the 15th February, 1879, to 6th June, 1879, and from 12th June, 1879, to 13th November, 1879, or 264 days.

The remaining series (F) was exposed in the boiler of a steam-collier running between Newcastle and London from the 23d May, 1879, to the 23d April, 1880, or 336 days.

No zinc was used in this boiler, and the water was taken from a point in the Tyne where it is probable that the refuse from one of the local chemical works acidulates it considerably. The boiler was emptied once in ten weeks, and steam was kept up for four days out of every five.

After the completion of the exposure the scale and rust were removed as carefully as possible by scraping and brushing the disks with a file card, and each one was again weighed at the Greenwich College with the same nicety as in the first place, and the results follow in a tabulated form.

BRIGHT DISKS.

Table I gives the loss of metal per square foot per annum. This was obtained by dividing the total loss of weight of each disk by its exact area (about $\frac{1}{4}$ of a square foot) and by the total period during which each set was exposed, which includes the time that the boilers were empty or not in use.

Table II was compiled from Table I by dividing each of the losses in the different columns by the loss of the respective Lowmoor plates, so that the different sorts of iron and steel can be readily compared.

Looking at Table II, under the heading of "Cold Water," and in the third column, which gives the mean values of the relative losses in the sea and bilge water, it will be seen that there are but two metals—Bowling iron and Messrs. Brown's steel—which corroded more than Lowmoor iron; and, although the average loss of steel is a little greater than that of iron, the difference is so slight that for practical purposes it is safe to assume that bright steel, exposed to the sea or bilge water, corrodes no faster than bright iron, especially than the better qualities of iron. When exposed to the atmosphere, although there is no great difference between the common and the better sorts of iron, the steel appears to have lost considerably more than either Lowmoor or any other iron; and the same is the case with those disks exposed to the action of boiler-water with or without zinc. But although the absolute losses of both iron and steel is least, the relative difference of losses of steel and iron is greatest in the boiler in which zinc is used. Here the steel has lost about 50 per cent. more than Lowmoor iron, and Lowmoor iron 50 per. cent. more than Bowling iron, or 40 per cent. more than the average of the other irons. On referring to Table I, column 4, it will be seen that the average losses per square foot are very small, and that the greatest loss of steel (Messrs. Brown's) in the boiler with zinc was less than the smallest loss of iron (Bowling) in the air, and far less than the Bowling iron in the other two boilers.

TABLE I.—*Absolute loss of iron and steel in pounds per square foot of bright surface per annum.*

	Cold water.		Atmosphere, London.	Boilers.		
	Sea. B.	Bilge. C.	A.	Zinc in boiler. D.	Collier boiler. F.	P. & O. boiler. E.
Parkhead common iron	.190	.415	.156	.058	.566	.195
Skerne common iron	.137	.556	.151	.062	.485	.203
Common iron mean	.163	.485	.153	.060	.525	.199
Leeds forge best iron	.168	.475	.169	.061	.609	.164
Taylor's best iron	.198	.527	.155	.066	.657	.191
Bowling best iron	.225	.518	.150	.052	.598	.193
Farnley best iron	.173	.573	.167	.069	.708	.217
Lowmoor best iron	.212	.539	.166	.087	.597	.209
Best iron mean	.195	.526	.161	.067	.633	.194
Landore mild steel	.208	.480	.206	.120	.666	.234
Brown & Co.'s mild steel	.215	.560	.254	.147	.755	.310
Bolton Co.'s mild steel	.198	.544	.214	.117	.785	.250
Steel Co. of Scotland's mild steel	.207	.509	.222	.132	.739	.253
Mild steel mean	.207	.523	.224	.129	.736	.262

NOTE.—A loss of 1 pound per square foot per annum is equal to an average loss of $\frac{1}{40}$th inch of thickness per annum.

TABLE II.—*Comparative loss of iron and steel, taking loss of Lowmoor iron as standard.*

	Cold water.			Atmosphere, London.	Boilers.				Mean of columns 1, 2, 4, 5, 7 and 8.
	Sea. B.	Bilge. C.	Mean of B, C.	A.	Zinc in boiler. D.	Mean of F, E.	Collier boiler. F.	P. & O. boiler. E.	
Parkhead common iron	.90	.77	.83	.94	.67	.94	.95	.93	.86
Skerne common iron	.64	1.03	.83	.91	.72	.89	.81	.97	.85
Leeds forge best iron	.79	.88	.83	1.01	.70	90	1.02	.78	.86
Taylor's best iron	.93	.98	.95	.93	.76	1.00	1.10	.91	.90
Bowling best iron	1.06	.96	1.01	.90	.60	.96	1.00	.92	.91
Farnley best iron	.82	1.06	.94	1.00	.79	1.11	1.19	1.04	.98
Lowmoor best iron	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Landore mild steel	.98	.89	.93	1.24	1.38	1.12	1.12	1.12	1.12
Brown's mild steel	1.01	1.04	1.02	1.52	1.69	1.37	1.27	1.48	1.33
Bolton mild steel	.93	1.01	.97	1.28	1.35	1.25	1.31	1.20	1.18
Steel Co. of Scotland mild steel.	.97	.94	.95	1.33	1.52	1.22	1.24	1.21	1.20

Table III shows the results of the analyses of the several bright disks contained in series F.

TABLE III.—*Analyses and densities of the respective materials of which the disks were made.*

Description of metal.	Manganese.	Carbon-color test.	Sulphur.	Phosphorus.	Silicon.	Copper.	Cobalt and nickel.	Density.
Parkhead common iron	trace.	.09	.027	.316	.020	.060	.15	7.618
Skerne common iron	.01	.10	.027	.193	.100	.021	....	7.705
Taylor's best iron	trace.	.12	.005	.136	.013	.00	.05	7.745
Leeds forge best iron	.03	.14	.028	.085	.110	.031	....	7.764
Bowling best iron	trace.	.11	trace.	.101	.100	.016	....	7.791
Farnley best iron	.01	.11	.012	.096	.090	.016	....	7.779
Lowmoor best iron	.01	.10	.022	.142	.120	.022	....	7.689
Landore mild steel	.64	.18	.074	.077	.013	.015	....	7.861
Brown & Co.'s mild steel	.11	.12	.077	.056	trace.	trace.	....	7.854
Bolton & Co.'s mild steel	.52	.19	.068	.041	.060	trace.	....	7.849
Steel Co. of Scotland mild steel	.26	.10	.035	.057	.032	trace.	....	7.872

NOTE.—The disks analyzed were the bright ones of series F, which, as already stated, was suspended in a boiler supplied with water from a point in the Tyne where it is probably acidulated by the refuse from one of the local copperworks.

Returning to Table II, we observe in column 9 that the steel, with one exception, has on an average corroded only about 14 per cent. more than Lowmoor iron, which has always been considered as amongst the most suitable for the internal portions of boilers, and which has corroded about 20 per cent. more than the ordinary irons. So that, although the present experiments confirm the prevailing impressions that bright mild steel does corrode faster than iron, when we get from the condition of a marine boiler to cold sea and bilge water, the difference is not so great as to establish the matter beyond question. I have here specimens of the steel and iron disks out of the boiler containing zinc. You will observe that the surface of these specimens is only a little rough, and that the corrosion is very uniform, which is the case with all the bright plates exposed in this boiler.

The plates exposed to the atmosphere are slightly rougher, but also uniform, while those suspended in the boiler of the Peninsular and Oriental Company's vessels are roughly and more irregularly corroded. It is not a little surprising to find that it is only amongst the disks exposed in this boiler and those exposed to the bilge water that any deep pitting has taken place. There were four cases, of which I produce two specimens (Nos. 3 and 4), which are very distinctly pitted. These were Farnley iron and Messrs. Brown's steel. The one contains a pit mark about $\frac{1}{16}$th of an inch deep, and the others pit marks not quite so deep. The plates submerged in the sea were irregularly attacked and rather patchy. Those exposed to the bilge water looked still worse, the black plates now and again containing pit marks, and the fibers of the iron in many cases being distinctly visible. (See samples Nos. 5 and 6.)

The plates exposed in the boiler of the coasting vessel had accidentally come adrift, and the insulation was thus destroyed within the last ten weeks of their immersion, and they do not show the action of the water so distinctly as in the other cases. No pitting has occurred, but the structure of the iron has in one or two instances been conspicuously brought out. (See sample No. 7.) The Lowmoor disk placed in this boiler also showed very marked projections, one of which, about two square inches in area, contained a thin red scale of what proved by analysis to be copper.

A comparison of Tables II and III, which could trace the relation of the different impurities contained in commercial iron and steel to their corrosion, would be of great interest, but the rate of corrosion has been so varied, even in the same series, and the amount of impurities are so slight, that I have not been able to determine the effect of the different elements.

A comparison of the densities and the corrosion shows the very reverse of what might have been expected from Mr. Mallet's experiments, for though they stand in no relation in series B and C, it appears as if in all others the denser metal has corroded fastest.

The hardening of the plates, by punching the numbers, in no way affected the corrosion of the bright disks, but the glass ferrules protected the part of the disk with which they were in contact when exposed to the atmosphere and bilge water. Curiously enough, however, in some of the cases in the boiler containing zinc, and in the sea, there was found to be considerable extra corrosion in the neighborhood of the glass.

BLACK DISKS.

With the black disks the glass had also protected parts of those disks subjected to the influence of bilge water and the atmosphere, while it had caused strong local corrosion on every one of the disks immersed in the sea and on about half of those exposed in the boiler containing zinc; and perhaps a still more curious circumstance is that throughout the experiments in the boilers the glass ferrules and glass tubes wasted more than the metals, being reduced to about half their original thickness.

The stamping of the numbers, which unavoidably caused some of the scale to come off, had an injurious effect on the plates exposed in the sea and the bilge, although the local corosion from this cause was only slight in all the other cases.

TABLE IV.—*Ratio of unprotected metallic surface of black disks to total surface after exposure.*

	Cold water.		Atmosphere, London.	Zinc in boiler.	Hot water.		Mean of columns 1, 2, 3, 4.
	Sea. B.	Bilge. C.	A.	D.	Collier boiler. F.	P. & O. boiler. E.	
Parkhead common iron	.70	.80	1.00	.60	1.00	1.00	.77
Skerne common iron	.30	.50	.90	.50	1.00	.90	.55
Leeds Forge best iron	.45	.85	.85	.80	1.00	1.00	.79
Taylor's best iron	.25	.50	.70	.30	1.00	.90	.44
Bowling best iron	.50	.90	1.00	.70	1.00	.95	.77
Farnley best iron	.30	.80	.95	.80	1.00	1.00	.71
Lowmoor best iron	1.00	1.00	1.00	.95	1.00	.98	.99
Landore mild steel	.30	.60	.50	.35	1.00	.90	.42
Brown's mild steel	.50	.80	.97	1.00	1.00	....	.82
Bolton mild steel	.15	.80	.50	.70	1.00	1.00	.54
Steel Co. of Scotland mild steel	.40	.80	1.00	.70	1.00	1.00	.72
Mean loss of scale due to stamping and exposure, exclusive of Lowmoor.	.38	.73	.74	.54	1.00	.96	....

TABLE V.—*Ratio of average depth of corrosion of black disks to bright disks.*

	Cold water.		Atmosphere, London.	Zinc in boiler.	Hot water.	
	Sea. B.	Bilge. C.	A.	D.	Collier boiler. F.	P. & O. boiler. E.
Parkhead common iron	1.2	.9	1.1	1.8	.9	1.0
Skerne common iron	3.3	1.2	.8	2.1	1.0	.5
Leeds Forge best iron	2.4	1.0	.8	1.6	1.0	.8
Taylor's best iron	3.1	1.1	.8	3.1	1.1	.6
Bowling best iron	1.8	.8	1.0	2.5	1.1	.9
Farnley best iron	3.0	.5	.9	1.3	1.0	.9
Lowmoor best iron	.9	.9	1.1	1.3	1.1	.9
Landore mild steel	3.0	.9	.7	1.8	1.2	.9
Brown's mild steel	1.8	.9	1.0	.9	1.0	....
Bolton mild steel	.6	.6	.5	1.0	.9	.9
Steel Company of Scotland mild steel	2.2	.8	1.1	1.1	1.0	1.1

To enable us to compare the corrosions of the black plates, it is necessary to divide the loss they sustained not by the total surface of the disks, but by the surface of the bare metal only. The percentage of exposed to total surface of each disk was therefore ascertained as nearly as possible, and will be found in Table IV.

A perusal of this table shows that, neglecting Lowmoor iron, which lost almost all its scale, the least scale has come off those disks immersed in the sea, namely, about 30 per cent.; next comes the series D, which was exposed in the boiler containing zinc, with 50 per cent., followed by the two sets exposed to the atmosphere and in the bilges with an average of 70 per cent., while the plates in the boiler of the Peninsular and Oriental steamer lost 95 per cent. Those suspended in the boiler of the coasting vessel lost all their scale, but this is easily accounted for by the fact that the glass ferrules broke during the last ten weeks of the exposure, thus allowing the disks to rub against each other.

Taking the mean values of the figures in columns 1, 2, 3, and 4, it will be seen that the Lowmoor iron has lost all scale; that Bowling iron, Leeds Forge iron, Parkhead iron, and Brown's steel have lost about 80 per cent.; Farnley Iron and Steel Company of Scotland steel about 70 per cent.; Skerne iron and Bolton steel about 55 per cent.; and Taylor's iron and Landore steel about 40 per cent. It should be mentioned, however, that in stamping the numbers before the experiments, it was observed that the Lowmoor scale appeared to be the softest, and fell off more easily than any other, while the other scales adhered better, but with different degrees of tenacity.

With the help of Table IV, and the accurately ascertained loss of each blank sample, and also the losses per annum per square foot of bright samples as given in Table I, we are able to compare the average depth of corrosion of the bright disks and that of the black disks where the scale has been removed. These results are given in Table V.

Looking at Tables IV and V, it will be seen that the black disks which lost least scale, have corroded to a greater depth than the corresponding bright disks, and this can only apparently be accounted for by the galvanic action set up. The relative size of the exposed and protected (black scale) surfaces must have had some influence on the galvanic currents, but they appear to have been considerably affected by the different fluids to which the disks were exposed. If we thus assume that the black disks which corroded to a greater depth than the bright ones were acted upon galvanically, it would appear as if those in series D, which was exposed in the boiler containing zinc, had suffered more from galvanic action than the black disks in the other boilers, while the samples immersed in the sea suffered more than those exposed to the greasy water and moist air of the bilges, although the absolute loss of the respective bright disks was less. There is no practical difference between the loss of the black and of the bright disks exposed to the atmosphere, and it is evident that here at least no galvanic action could have taken place.

Without knowing how long the scale had been off, it is of course impossible to form a correct measure of the rate at which the black oxide might have been acting galvanically upon the neighboring bare patches, but the comparison is worth making, so far as it goes, and it certainly tends to confirm the belief mentioned by Mr. Barnaby and others, that a rather strong galvanic action does go on between the scale and the patches of bare metal in its neighborhood. Looking to the importance of this point, it is to be hoped that it will be further followed up and scientifically analyzed, as it seems to be from these experiments of quite as much importance as has been attributed to it.

As regards the protection afforded to the disks of series D, suspended in the boiler containing zinc, and, like the others, properly insulated from external galvanic action, the results would seem to indicate that this protection is due, not, as is generally supposed, to the galvanic action of the zinc, but either to the zinc salts, which gradually impregnate the boiler water, and possibly impart to it anti-corrosive properties, or to the action of the zinc, which, as it corrodes, absorbs all corrosive agents contained in the water. It would be interesting to ascertain by experiment what is actually the effect of dissolved zinc salts in boilers.

I have now endeavored to lay before the meeting the results of the series of experiments which it has been my privilege to make. I do not for a moment pretend to be able to account for all peculiarities that have arisen. Some degree of capriciousness was to be expected from those plates on which the scale was left, but I must confess I was hardly prepared to see so much difference between different steels and between different irons under precisely similar conditions as proved to be the case. It would perhaps not be far wrong, speaking generally, to say that the different pieces of iron differed as much among themselves as they did from steel; and certainly the effect produced on my mind, after carefully weighing the results of the experiments, has not been to raise any apprehension that steel boilers or steel ships are likely in the future to corrode to any serious extent more rapidly than iron.

Having made these experiments, however, I desire to say that I do not think undue importance should be attached to any experiments of the kind made on a small scale. The most they can do is to indicate tendencies and perhaps suggest remedies and precautions earlier than actual experience, which necessarily takes some years to accumulate when a new material is placed under trying conditions. The only real test, however, and the only one that will be finally accepted, is that of practical experience with the boilers themselves.

We have at the present time some 1,100 marine steel boilers running, the majority of which come periodically under the inspection of the engineer-surveyors of Lloyds' Register, and although they have received instructions to give these boilers special attention and to note carefully any peculiarities they may discover, the accounts I have received from them down to the latest go to show that the steel boilers behave in respect to corrosion about as well as iron boilers. In one or two vessels also where an iron and a steel boiler are working under identical conditions, there is nothing to point to the conclusion that the iron will outlast the steel one. Greater irregularity in the corrosion of the steel is reported, and I am inclined to the belief that this is due, even to a greater extent than shown in the experiments, to the unequal action of the scale, and if it should be found necessary hereafter to remove the scale, the difficulties in the way would not be great, and much of the irregularity and pitting would doubtless be removed. This I know is being done to a limited extent in boilers. The Admiralty also have taken steps to remove the black scale from their ships, and I have heard of at least one firm intending to follow their example. At any rate, I feel sure this meeting will hear with satisfaction that neither from the series of experiments which I have described, nor from our daily experience up to the present time, is there any reason to believe that the question of corrosion is likely to form a bar to the extended use of steel for marine boiler-making purposes. Difficulties may arise, and some unexpected results may be found, but the difficulties will, in my opinion, be easily removed, and the members of this Institute will, I am sure, welcome any one who will lay before them unexpected results, and will assist him in obtaining an explanation of them.

The President here announced the receipt of a letter from Lord Granville. His lordship wrote to say that he would have attended their meeting that morning if he had not been detained at a cabinet council.

ON THE ECONOMICAL ADVANTAGES OF STEEL SHIPBUILDING.

BY MR. WILLIAN DENNY, *Dumbarton.*

Steel for shipbuilding has been lately treated in so many aspects that one can hardly hope to add much in the way of novelty on the subject. The methods of working the steel, the tests to which it should be subjected, and the corrosion to which it is liable, have all been considered, but there are still two points which have not as yet received anything like the treatment they deserve. The first of these is as to the arrangement of structure best suited to the new material. At present it is certainly not getting fair play in being treated very much as iron is treated. There should be a decided difference in the proportions of the scantlings, owing to the difference of nature in the material, and not merely a reduction of these scantlings. The second point which has received as yet insufficient treatment is that comprised in the title of this paper, *i. e.*, the economical advantages involved in the use of steel for shipbuilding. This subject was touched upon by Mr. Martell in a paper read by him before the Institution of Naval Architects in 1878, and entitled "Steel for Shipbuilding." It was, however, only incidentally treated, and the views expressed by Mr. Martell upon it were, as pointed out by several speakers in the course of the discussion, of too sanguine a nature.

In his estimate of the extent of the reduction, Mr. Martell assumed that the saving on the weight of iron required for building a steamer of 2,300 tons gross was over 18 per cent. as between the steel and iron. In a sailing ship of 1,700 tons gross he assumed a saving of 19 per cent. There is no doubt the saving would be greater in the sailing ship than in the steamer, owing to the greater amount of material employed structurally therein, but the saving in both cases was over estimated.

The experience of my firm is that by building a steamer of steel in stead of iron, a saving averaging 13½ per cent. upon the weight of the iron can be effected. The variation in the percentage is very slight, the highest saving we have yet made amounting to a little over 14 per cent., and the lowest to 13 per cent. In Appendix A are given the items of the invoiced iron weight of a spar-decked steamer of about 4,000 tons gross, with their cost at present current prices of iron, and in the same appendix are given the same particulars for the vessel constructed of steel. You will notice that the amount of the invoiced iron in the iron steamer is 2,333 tons, and of the invoiced iron and steel in the steel steamer 2,030 tons, the difference being as nearly as possible

13 per cent. upon the weight of iron. This is rather less than the average reduction mentioned above, and the dimunition of the percentage is due to the fact that in a spar-decked vessel, the iron scantlings being already to some extent reduced, it is impossible in employing steel to reduce them in the same ratio as in a three-decked or full-scantlinged vessel. In the case of an awning-decked steamer, which, as compared with a three-decked vessel, is further reduced in iron than a spar-decked steamer, the percentage of reduction in steel would even be slightly under 13 per cent., and for similar reasons. You will notice that in the weight of iron and steel, required for building the steel steamer, there are 340 tons of iron which are employed in the building of deck-houses, coal-bunkers, engine and boiler casings, coal-shoots, coamings, and engine and boiler seatings. On this no reduction is made; and if we add to this weight 41 tons of forgings, which, although of scrap steel, it is not the practice of my firm to reduce, we have 381 tons of the original iron weights not subject to any reduction, thus leaving only 1,952 tons subject to reduction.

If we assume the amount of reductions permitted by Lloyds' to be 18½ per cent. upon scantling sections, we will not be very far wide of the mark, as although the rules permit a reduction of sectional area of 20 per cent., and in some cases a little more on certain portions of the structure, on other portions, such as the beams, frames, and reverse frames, it is impossible to approach this. If we now deduct from the 1,952 tons of iron subject to reduction 18½ per cent. for reduction of sectional area, we have 1,591 tons; but this weight has to be increased by 2½ per cent., the amount of the difference of weight between equal volumes of mild steel and iron. This adds 40 tons, making the correct weight 1,631 tons. Adding to this the 381 tons of iron common to both the iron and steel steamers, we have a total of 2,012 tons, or very nearly the correct amount estimated in Appendix A as the weight of the steel and iron in the steel steamer.

As the weights we have been discussing are the invoiced weights, to arrive at the difference of dead-weight capacity it is necessary to deduct from them 9 per cent. for scrap. This leaves the weight of iron actually worked into the iron steamer at 2,123 tons, and the weight of steel and iron worked into the steel steamer at 1,847 tons, giving a difference of 276 tons, which would be the increase of dead-weight capacity. This is, as nearly as possible, 7 per cent. on the gross register tonnage of the steamer, and any one desirous of arriving at the increased weight capacity which would be obtained by building an iron steamer in steel to Lloyds' classification can do so very simply and with fair certainty by estimating it at from 7 to 7½ per cent. of the gross tonnage of the vessel. Coming now to the relative cost of the steamer, we have in consideration built of iron, as against the same steamer built of steel, you will notice that this is shown in Appendix A as being the difference between £14,501, the net cost of the iron in the iron steamer, and

£18,075, the net cost of the iron and steel in the steel steamer, or a difference of £3,574, by which the cost of the steel steamer would exceed that of the steamer built in iron. This is stating the matter very favorably for the iron, as it will be seen from a note that with iron plates of the dimensions used in the steel vessel, extra payment of £650 would require to be made. This is caused by the very restricted limits imposed by ironmakers on shipbuilders, under penalty of severe extras. A very much more liberal and wise course has been pursued by the steelmakers, and to the Steel Company of Scotland belongs the credit of initiating this policy. Practically they leave us unlimited, and thus encourage that development of improved construction in which greater length of plates is an important factor.

To give, however, every advantage possible to the iron, we will assume the extra payment would not be enforced, and that the difference of cost would be, as already mentioned, £3,574. Dividing this amount by the increase of dead-weight capacity, 276 tons, we have the extra dead weight costing £13 per ton. In the case of the steamer we are considering, which is a high-class, fast-speed, passenger steamer, with the combination of good carrying power, this increase is undoubtedly very cheaply obtained. Such steamers are generally, if anything, short of dead weight capacity, owing to the heavy weight of their fittings and machinery, and to the considerable amount of coal they are compelled to carry. If we assume, and we may fairly do so, that such a steamer would make three and a half round voyages from London to Calcutta and back in the course of the year, that is, seven single voyages, and if upon each of these voyages we estimate the freight earned per ton of dead weight capacity at 20*s*., then we shall have each ton of increase earning £7 per year, or in two years £14. From this falls to be deducted the cost of marine insurance, which would not amount to more than 7 per cent. per annum, or say 36*s*., leaving £12, 4*s*. as the net earnings per ton in two years; that is to say, very nearly the entire cost of the extra dead-weight capacity would be cleared off in that time.

This is a conclusive proof that even at the present prices it is advantageous to build such a class of steamers in steel. That this argument is appreciated by the great steam companies is proved in the case of the London and Calcutta trade by the fact that all the latest orders of the Peninsular and Oriental Steam Navigation Company and the British India Company, the two leading lines of steamers upon that route, have been for steel vessels. At the present moment these companies are building between them nine steel steamers of over 4,000 tons gross.

If we now take the case of a steamer of less size and plainer description, we shall find that the advantageous results are not very different. In Appendix B a comparison is made between a steamer of molded dimensions, 310 by 38 by 27.5, built in iron to Lloyds' highest class under the three-decked rule, with poop, top-gallant forecastle, and midship houses, and a steamer of similar proportions and of such a reduction in size as will carry the same dead-weight built in steel. The ratios given along with the particulars of these two steamers show that their proportions with regard to dimensions and draft are identical. In each case the molded breadth is assumed as the unit, and the length, breadth, and draft are expressed in coefficients of it.

The displacement coefficient is that of general use, and the weights of iron, steel, and other items involved in the construction of the hull, and also the tonnage, under deck, are expressed in ratios of what is known among shipbuilders as the cubic number. This number is produced by multiplying together the molded dimensions and dividing by 100, and is a fair basis for the comparison we are making. The reduction of the iron weight in this class of steamer is assumed at 14 per cent.; the difference between the coefficients .45 and .387. As worked out in the table, you will notice that it is possible in a steamer built of steel of molded dimensions, 305 by 38.4 by 27.05, and with a molded draft of 21.15 feet, to carry the same dead weight as in an iron steamer of 310 by 39 by 27.5 with a molded draft of 21.5 feet.

You will notice that not only is the draft reduced by fully 4 inches by the use of steel, but a saving of 81 tons is made in the net register tonnage upon which dues are paid. The difference in cost between the two steamers is shown by multiplying the invoiced iron of the iron steamer, 1,496 tons, by £6.217, making £9,298, and the 1,226 tons of iron and steel in the steel steamer by £8.9, making £10,911, the price per ton being taken as in Appendix A; the difference between these two costs is £1,613 against the steel steamer. The cost of the steel steamer would, however, be reduced, owing to its smaller size, by fully £400 in outfit, general woodwork, and other items, and by £300 in the cost of iron labor; in all, by £700. The difference of cost, therefore between the two steamers would be as nearly as possible £900 extra on the steel steamer. For this extra money a decrease of draft and of taxable tonnage would be obtained. It will be interesting for steel manufacturers to know the exact net price at which steel would be required to be sold overhead so as to make the steel steamer we have under consideration identical in price with the iron steamer. To arrive at this, we must divide the cost of the iron in the iron steamer £9,298, plus £700, the extra cost of that steamer in other respects over the steel steamer, in all £9,998, by the weight of steel and iron, 1,226 tons. Doing this, we obtain an average price of £8.15. This is 15*s.* per ton under the average already obtained, for iron and steel together, from prices at present ruling; and by assuming that the ratio of iron to steel in the steel vessel of Appendix B is the same as in the steam vessel of Appendix A, we may find what the price of the steel alone would have to be, the iron—including also the forgings—remaining as at present. That price becomes £8.28, or about 20*s.* below the current price now ruling. Before dropping the comparison of the two steamers shown in Table B, it is worth while to discover what would be the extra cost and increased dead weight of the iron steamer built in steel without change of dimensions. If we deduct from her invoiced weight of iron 1,496 tons, 14 per cent., or 209 tons, which in this case is a fair allowance, owing to the iron scantlings being full size, we shall have for her steel and iron weights 1,287 tons, and for the relative cost—

1,496 tons at £6.215	£9,298
1,287 tons at 8.9	11,454
	2,156

Deducting 9 per cent. for scrap from the difference, 209 tons, we have 190 tons increase of dead weight at a cost of £2,156, or £11.35 per ton. This is about £2 per ton over the cost per ton of the dead weight capacity obtained in ordinary plain dead-weight carriers; but looking to the fact that only insurance and depreciation would be charges against this price, and that neither coals, current expenses, nor dues come against it, there is no doubt the increase on dead weight would be a source of very decided and clear profit in the working of the steamer.

That it is possible a considerable reduction on the price of steel may be soon obtained is shown not only by the fact of the great reduction in the price of it which has taken place lately, but also by experience; my firm having on one occasion during the late depression purchased several thousand tons of steel, manufactured by one of the best works in the country, at the price of £8 17*s.* 6*d.*, less 2½ per cent., equal to a price of £8 13*s.* net. My own opinion regarding the price of steel is that it must steadily lower until it reaches an equality with the price of iron. I am led to this conclusion not only by the fact that such a lowering of price has taken place in the case of steel rails as compared with iron rails, but also because I am told the methods of steel manufacture are capable of more economical development than the system of puddling employed in making iron. It may, of course, be answered that the amount of testing, and the careful records required to be kept by the steel-maker of the nature of his material and its character as it passes through the different processes, involve a considerable amount of expense not thrown upon the iron manufacturer. No doubt this objection has relevancy, but as the difficulty involved in it is to a great extent one of organization, I believe that it will be overcome with much less expense than is at present anticipated. There is a great fear on the part of many manufacturers of such an organization as will be required for the careful and successful manufacture of steel for ship-building and boiler-making purposes. They dread the consequences of red tape, but they have no occasion whatever to fear such consequences if they will only regard such organization in a proper light, as a thing which is to be perfected day by day and month by month. The evil of red tape is the assumption that an organization once set down is fixed and perfect. Such a view is an indolent and dangerous one; but if we admit the truth that organization must be subject to the same law of progress as the changes in manufacture, we shall avoid all danger of red tape. Any way it is certain that if good and reliable steel is to be produced, the manufacturers of it will not only be subjected to a greatly increased amount of testing of a more crucial nature than at present, but that they must themselves be more severely critical of their own productions. It is in such a spirit that the two or three leading steel companies, whose material can be almost absolutely relied upon, have obtained their success; and it is only by following in the same course that the production of such steel as failed in the *Livadia's* boilers, and as my firm had the misfortune lately to be troubled with, can be avoided. Mr. Parker's paper read at the late meetings of the Institution of Naval Architects fully described the peculiarities of this material, and I would only remark that it would be better for steelmakers to discover the faults of their own material before permitting it to be invoiced than to have them discovered in process of working. The responsibility lies with them to produce good material, because we know that there are steel-works which can with practically unfailing regularity produce such steel.

In treating of the difference of cost between an iron and steel steamer, I did not mention the fact the rates for riveting steel rivets are, in our district, 5 per cent. higher than those for riveting iron rivets. It might be assumed from this that the labor on a steel steamer would be, as a whole, more expensive than the labor on an iron steamer of the same size. This, however, is not so, because, excepting in the cases where the steel is of the unreliable nature already referred to, it is much cheaper to work than iron, on account of the lighter weight of the pieces, the greater liking of the workmen for the material, and the certainty a shipbuilder has that he will have no wasted labor from failures in workmanship. So fully recognized is this fact that, in yards where not a steel ship is building, it is now common to find steel plates at more expensive prices ordered instead of "best best" plates for the difficult portions of the ships, such as boss-plates, tuck-plates, round-over of stern-plates, the bosses for twin screws, &c. While visiting a very small yard lately, I observed they were using steel for such purposes in an iron ship then building. On asking the reason why, the answer was that its use was far more economical in the matter of labor, thus more than making up for the difference of price.

It must be remembered that in a busy time, such as the present, the failure of, say, a number of garboard and bilge strake plates, which happens pretty frequently in a large iron steamer, is not only a loss directly in labor, but a loss indirectly owing to the restriction of output of work caused by it.

As to the future of steel, I think even those who up to this point have been its opponents must admit that there can be very little doubt of its prospects. It has much in its favor, and requires only some little self-restraint and self-denial on the part of steel manufacturers to bring about its ultimate and complete success. If these gentlemen, instead of trying to claim for themselves, as they sometimes do, a specialty in the manufacture, would set their whole energies to the reduction of the cost of the material, and at the same time to the perfection of its quality, there would be little doubt about the future. Steel of an unreliable quality has been made, and may be made in the future; but it will be, as in the past, the exception, and I believe in every succeeding year a rarer exception. So far steel has fought its way in the face of many doubts and difficulties, and has gradually acquired the confidence of the public in the main points of facility of workmanship and of reliability. I believe this reliability will in the future, when it becomes sufficiently appreciated, enable a steel ship to be insured at a less cost than an iron ship, as the risk she runs either in collision or in grounding or running on a rock is very much less. In a paper I had the honor to read before the Institution of Naval Architects last year, I gave an example of this in the case of the *Rotomahana*, a steamer built by us for service in New Zealand. According to the opinion of competent judges, had this vessel been built of iron she would have been a total loss instead of being, after running upon a rock, not only sound and water-tight, but very easily repaired.

The facts as to the economics of the subject which I have had the honor of bringing before you on this occasion prove that upon this point steel has in the higher class of steamers a clear advantage, and that even in the case of heavy-cargo carriers of moderate speed the advantage is decided. It is scarcely credible that the makers of steel, who up to this date have shown such enterprise and skill, will permit the question to remain for any length of time in a state of doubt. It is rather to be expected that they will see that a moderate cost of production combined with excellence of quality is the whole secret of their future. If we turn to the records of Lloyds, we find that during the last three years the progress of steel shipbuilding has been of even a more rapid nature than might have been anticipated. In 1878 there were classed at Lloyds 4,500 tons gross of steel shipping; in 1879 this amount rose to 16,000 tons gross, and last year to 35,400 tons gross, showing that in three years the output of steel shipping classed at Lloyds had increased eight times. This year on the 1st January, Lloyds had building to class 83,000 tons of steel vessels, and throughout the United Kingdom, inclusive of the above, 114,000 tons of steel vessels were known to be building.

Regarding steel, there has been only one doubt raised this year, and that is as to its corrosion. My opinion is that the doubts and fears on this head have been largely exaggerated. Theoretically there may seem cause to dread such corrosion, but the history of steel ships up to this date affords little ground for the opinion. Of the steel vessels built by my firm, only one, and that a small twin-screw, has been reported as in any way showing even a symptom of corrosion. That this was purely exceptional is shown by the fact that several other steamers of the same material have been running in the same waters, and with the most satisfactory results, no more mention of corrosion being made even in the case of the original steamer. Of the seagoing steamers built by my firm only one has shown any corrosion, and that has not been in the steel, but in the iron stern-frame and rudder forgings and in some small iron plates on the rudder, the large steel plates of the rudder and the whole shell plating of the ship, which is of steel, being perfectly free from corrosion.

I do not wish to take up your time at greater length with the details of these matters, as you will find them fully noted in the "Transactions of the Institution of Naval Architects," but will simply state my belief that, as steel has conquered the doubts that beset the outset of its progress, it will with equal certainty overcome this last doubt, which, for all practical purposes, is as groundless as those which preceded it.

APPENDIX A.

Cost of iron required in a spar-decked steamer of 4,000 *tons gross.*

	Tons.			
Plates, angles, and bulbs	2,098	at £	6.0	£12,588
Slip iron	52	at	5.5	286
Round and bead iron	31	at	6.5	202
Forgings	41	at	25.6	1,050
Rivets	111	at	10.0	1,110
	2,333			15,236
Less 9 per cent. scrap	210	at	3.5	735
	2,123			14,501

Cost per ton of invoiced weight $\frac{£14,501}{2,333} = £6.25$

N. B.—Owing to the plates in this steamer being 16 feet long, 610 tons of them exceed the limits allowed by iron-makers in size and weight, and on this an extra payment of £650 would be required. The true cost of the iron would therefore be £15,151 instead of £14,501. The limits allowed by the steel-makers would entail no extras on this vessel.

Cost of iron and steel required in same steamer built of steel.

	Tons.			
Iron plates and angles	244	at £	6.0	£1,464
Slip iron	49	at	5.5	270
Round and bead iron	31	at	6.5	202
Rivets	16	at	11.0	176
	340			2,112
Steel plates, angles, and bulbs	1,569	at	9.25	14,513
Forgings	41	at	25.6	1,050
Rivets	80	at	13.0	1,040
	2,030			18,715
Scrap 9 per cent	183	at	3.5	640
	1,847			18,075

Cost per ton invoiced $\frac{£18,075}{2,030} = £8.9$

APPENDIX B.

Comparison between a combined heavy-cargo carrier and passenger steamer for the eastern trade, built of iron, and a similar steamer built of steel to carry same amount of dead weight.

	Iron.	Steel.	Ratios.
Length between perpendiculars L......	310	305	7.95 x B
Breadth molded B......	39	38.4	B
Depth D......	27.5	27.05	.705 x B
Cubic No. $\frac{L \times B \times D}{100}$	3,325	3,168	
Draught molded	21.5	21.15	.55 x B
Displacement............................	5,580	5,308	.75
Invoiced iron	1,496	....	.45
Net iron	1,362	....	Less 9%
Invoiced iron and steel	....	1,226	.387
Net iron and steel	....	1,116	Less 9%
Other hull weights	598	570	.18
Machinery................................	263	255	
Total hull weight........................	2,223	1,941	
Dead weight capacity	3,357	3,367	
Displacement, as above................	5,580	5,308	
Tonnage under deck	2,453	2,338	.738
Poop, forecastle, &c......................	208	200	
Tonnage, gross	2,661	2,538	
Less propelling space, 32 per cent.......	851	812	
	1,810	1,726	
Less crew space	113	110	
Net register tonnage	1,697	1,616	
Saving in tonnage	81 tons.		

DISCUSSION.

The President having announced that the discussion on Mr. Parker's paper and Mr. Denny's paper would now be taken,

Mr. G. J. Snelus (Workington) remarked that he had twenty-five boilers under his charge, made partially or wholly of steel, some of which had been working eight or nine years, and so far as his experience went it bore out the view of Mr. Parker, that there was really no difference in the corrosion of steel and iron. In fact, they had saved a great deal of money by the difference in favor of steel. They had found some little difficulty in steel with pitting, and he was inclined to believe that pitting was to some extent due to the irregular diffusion of the manganese contained in the spiegeleisen. Those plates in which the pitting occurred most frequently were made by the old process, where spiegeleisen was used in soft steel, by the Bolton Steel Company. He was now instituting some experiments to see whether the pitting was not due to the irregular diffusion of manganese. The diffusion of the manganese now would probably be more uniform, as they were using it in a different way, and less of it. There was no practical difficulty with the corrosion of steel, which stood for all practical purposes as well as iron. He was pleased to find that Mr. Parker had not taken alarm on account of the remarkable paper which had been read six weeks ago in that room—a paper which attempted to show that the corrosion of steel was infinitely worse than that of iron. That was not the general view, but the experiments recorded on that occasion were so elaborate that many went away with the idea that that had been proved. With respect to Mr. Denny's paper, it hardly needed to be pointed out that while manufacturers were extremely wishful that the price of steel plates should be as low as that of iron, yet there was one difficulty the steelmakers would like Mr. Denny and others to help them out of. They began, in making a steel plate, with an ingot worth £5 per ton, and it took about 32 cwt. of ingots to make a ton of plates, including sketch plates. A considerable portion of that material, at £5 per ton, went back to the melting-furnace at perhaps £3 per ton. It was different in the case of iron. They began with a puddled bar at £4 per ton, and the scrap became a No. 2 iron, which was worth more than the puddled bar, and therefore the steel manufacturer was not in as good a position, with respect to the cost of making ship plates, unless they could find an outlet for the scrap nearer to the value of the ingot than they could at present have. If other firms would take the steel scrap and make forgings of it—as Mr. Denny did—that would be another matter. He had no doubt they would shortly get into a better position.

Mr. RICHARDSON (Oldham) said that they had sixty steel boilers in connection with the works of Platt Brothers at Oldham, some of which had been in use upwards of twenty years; in two-thirds of them there was no corrosion at all; in the other one-third a few cases had occurred whilst the boilers were supplied with water gathered from a district where the outcrop of the coal measures took place; but in all such cases the effect had been arrested by the application of zinc, which neutralized the acid taken out from the pyrites.

Professor ABEL, C. B., F. R. S., wished to express the satisfaction he felt with the contrast Mr. Parker's paper presented to the paper he had heard some time ago in that institution on the comparative durability of iron and steel for boilers. On that occasion they were asked to accept, upon what seemed to him very doubtful foundation, the conclusion that iron was inferior to steel as a material for boiler plates. On the present occasion, Mr. Parker had put forward the results of careful comparative experiments; and although given with great diffidence, he thought they conveyed to the mind of those in the habit of making scientific experiments the conclusion that value was to be attached to them. He thought they should all thank Mr. Parker for the instructive results he had brought before them and for the caution which he had given them, that they should not attach too much importance to results obtained on a small scale. Looking at the results generally, they might accept with considerable confidence the conclusion that no important advantage could be claimed for wrought iron over steel as a material for boilers.

Mr. WHITE, of the admiralty, said that he extremely regretted that Mr. Barnaby had been compelled to leave the meeting and return to the admiralty, and what he had to say must be taken in some measure as what Mr. Barnaby himself would have said had he remained. In the first place, he was glad to see that Mr. Parker had not put the word "admiralty" at the head of his tabular statement of experiments made by the boiler committee. It was an unfortunate thing for the admiralty, as a department, that that committee was generally described as the admiralty committee. In making this statement he did not wish to criticise their labors in the least. He would, however, say, that although the blue-book containing the committees' experiments had been before the public for some time, steel was in general use in the Royal Navy. The shells of the boilers for Her Majesty's ships were now usually made of steel, although certain parts were made of iron. His main purpose in rising was to say something about the use of steel for shipbuilding. Taking Mr. Parker's paper first, he did not think that Mr. Parker meant to convey any doubt of the possible influence of scale upon the corrosion of steel when he said that Mr. Barnaby had expressed a belief on the subject. That was not a speculative belief, but was a belief based upon experience and many careful experiments made under water in Portsmouth Harbor. The trials were made with the greatest care under the most varied conditions, and the results made it as certain as one could be certain about anything that the black oxide, if left on portions of steel plates, would cause pitting on the bared surfaces of the plates. Active galvanic action could be traced with the galvanometer on the parts of the plates from which the scale had been removed. There was all the difference in the world between corrosion and pitting, as Mr. Mallet's and Mr. Parker's papers, as well as the admiralty experiments, proved. Mr. Parker had shown that there might be practically no corrosion on clean surfaces during very long periods, but if a hole was formed in the plate by pitting it became a very serious matter. Corrosion could be dealt with in steel ships, but pitting sometimes gave trouble in admiralty ships, and gave trouble also to the mercantile marine. In the Royal Navy they were trying to get rid of the black oxide by means of pickling; that was to say, the important parts of the plates and bars were dipped in acid baths before being worked. Plates which had been worked on ships were also being dealt with by other means; but the process had not yet been perfected. If it were perfected it would be possible to scale bottom plates easily after they had been riveted, and to deal successfully with the removal of the scale from other plates and bars. They would, no doubt, ultimately be secured against pitting. In the private trade, where ships were built in the open air and exposed to the weather, he believed there was less difficulty in getting rid of this scale than in the case of the admiralty ships which were built under cover. The danger was, that they might have some local part to which the scale adhered after all care had been taken. In the case of the Iris and the Mercury, great care had been taken to get rid of this black oxide; but when the Iris had been on service in the Mediterranean a few months, it was found that the effects of the scale were visible. He desired to speak also as to the cost of steel compared with iron. It was worthy of notice that in the admiralty service—where they had always insisted upon testing the materials that they used—it was not long before steel became cheaper than iron. That was a fact which should be noticed, because it meant a very great deal both to them and to the mercantile marine. He concurred in Mr. Denny's opinion that makers of steel should decrease their prices as much as possible; but it must be noted that whereas in the mercantile marine formerly a regular systematic testing of iron was not practiced, now, with steel, it was practiced. Already in the Government service they could get steel cheaper than the high-class iron that they wished to have, and that had to undergo rigorous tests. He believed with Mr. Denny that steel manufacturers would find it to their interest to reduce the price of steel, if not to level it to the price of good iron. He did not suppose it could be reduced to the low price of some iron used in shipbuilding, and perhaps it was better that it should not be so reduced, but it might be made equal to the cost of iron such as Lloyds would pass, and such as builders of reputation would use. Finally, he desired to refer to the relative cost of working iron and steel. At the admiralty they had now had extensive experience with steel, and found that the working of steel was dearer than the working of iron. Their experience showed that the cost of riveting steel was more; and in welding, forming frame-jozzles, and doing other work at the forge, they found that steel was dearer than iron. But it should be remembered that in steel ships less weight had to be dealt with, and they must make allowances; for if one reckoned the labor cost per ton, he would put an apparent premium on the steel ship as regarded the cost of labor. Speaking broadly, the cost of labor on a ship of given form and bulk would be nearly the same if built in steel as if it had been in iron, the steel ship being considerably lighter,

Mr. B. Walker (Leeds) said that fifteen years ago his firm had made a number of Lancashire boilers, and he had advised that they should make one flue of steel. The steel was made by Messrs. Charles Cammell & Co., and when Messrs. Cammell knew that they were going to punch the steel, they said they could not supply it. He reminded them that they had informed him that their material was as good as Lowmoor iron, and it would have to receive the same treatment. Ultimately Messrs. Cammell made the plates of Bessemer steel, and put them into the Lancashire boilers, one flue being steel and the other iron. For years he had watched those flues to see whether there was any material difference between them, but he had given the investigation up because he never could find anything to show which was steel and which was iron. Every plate had been punched from the beginning to the end. Nothing had kept steel back more than the fact of its being made to order. The engineers had gone to too high a reach of tensile strain. If the tensile strain were lowered, steel would become a greater favorite both with the workmen and with the users; for it wanted sufficient elasticity so that it might be cnanged in form without detriment. Some twenty or thirty years ago, steel was so hard that in making the least change in form it led to destruction. Steel did not corrode more than iron, and they could do as much with it as they could with iron. They could make steel of such a quality that it would stand what iron could not stand in the way of bending into forms in the smith's shop and under the press. If they went to Woolwich, they would see there steel bent into the most fantastic shapes, such as could not possibly be made out of iron. He had no fear as to the ultimate everyday use of steel. As to what Mr. Denny had said about welding sixteen years ago, the old Bessemer tires were then in the market, and it was said that they would not weld. But his firm used to buy them whenever they could get them, and they never told the men that they were steel, but gave them out as old iron pile; and the men found no difference except that the stuff was better and tougher. He had no doubt that scrap would be bought from steel platemakers and would be repiled and made into bars and forgings of various shapes.

Mr. B. MARTELL (Lloyds' Register) said he could not help expressing his satisfaction at Mr. Parker's paper having been read on that occasion, because it was so opportune in view of the paper that had been read a few weeks ago before the Institution of Civil Engineers. Mr. Martell had said, when the paper alluded to was before them, that experiments such as those made on exceedingly small pieces of metal, under conditions that they were not exactly cognizant of, were unreliable, and could not be accepted by practical men interested in ships and boilers and who had actual experience. Lloyds' Register had had a great amount of tonnage built of steel, and they found that those experiments of Mr. Parker's were fully borne out as to the deterioration of that metal. From the careful experiments by the admiralty, as explained a few weeks ago by an admiralty official, it was clear that the black oxide was a primary cause of deterioration. Only a week or two previously he had been in the shipbuilding yard of Messrs. Denny, on the Clyde, and he there saw several steel ships that that gentleman was building. It was surprising to see the ease with which the scale, composed of black oxide, could be removed from the plates. When the plates were exposed to the air for some time the scale could be removed by the finger. There was no difficulty in dealing with this matter because there was only a little labor required in getting rid of the scale. With reference to Mr. Denny's paper, the weights which the author had taken the percentage of as showing the saving in the weight of steel ships were taken from ships actually built—one a small steamer having no deck erection or superstruction of any kind, and the other a sailing ship. The particulars had been given to him by a builder on the Clyde, well known to Mr. Denny, and he was much surprised to see that this small reduction of 13½ per cent. only could be counted on with regard to steel vessels as compared with iron, although it was explained by the difference in the types of the ships to a certain extent. If he had not seen the careful and accurate manner in which Messrs. Denny kept their accounts, he should have had some doubts respecting that point; but knowing how well their accounts were kept, they must accept the statements contained in the papers. But even with 13½ per cent. reduction, it was satisfactory to find that Mr. Denny showed that ships could be built of steel at the extra cost, and that it was thus a very good speculation for any one to go into. With regard to the safety of the ships and their efficiency, those of them who had had experience would agree with him in saying that iron was not on the same platform with it. It was an exceedingly superior material. He hoped steel manufacturers would be able to make this material more marketable by bringing it nearer the price of iron, so that to build a ship of iron would be almost as uncommon as to lay down iron rails upon their main railways.

Mr. EDWARD WILLIAMS said that, as to corrosion, he knew nothing that was reliable. He had endeavored to follow the several communications to scientific societies on the subject, but the result had been unsatisfactory. Some great authorities asserted positively that the amount of corrosion was much against steel, and other authorities equally great testified pretty much to the contrary. They had just had from Mr. Parker what to him, at least, was a most satisfactory statement; and he thought that until a man as competent as Mr. Parker had gainsaid him, they might be content to dismiss the question of corrosion as not likely to trouble those who make and use steel. He should like to say a word in favor of the platemakers, of whom Mr. Denny had but a poor opinion. Mr. Denny seemed to think that steel plates were dear because those who made them took little trouble to ascertain the cost of production and made small effort to bring down that cost, but in that opinion he was mistaken. There was no maker of plates in the country worth talking about who was not anxious to produce plates made of the best material at the very lowest cost. He did not, of course, pretend that there was no carelessness or that no mistakes were made; but he could say positively that the high price of steel plates was not in consequence of indifference on the part of the makers, or because they did not exercise their best energies to bring down the cost of production. Mr. Snelus had pointed out several items of the cost of steel plates that it would be difficult to get rid of, and he thought that the price of such plates would always be a good deal higher than that of iron plates unless action were taken in the way Mr. White had suggested, namely, to require a very high quality of iron. If this were done, there must be a great increase in the price of iron, which would, of course, thereby approximate that of steel. He was not advising this course, because, so far as he knew and believed, there was no serious allegation that iron of the quality in general use was not sufficiently good for the hull of a ship. With regard to boilers he had not a word to say, except that any man who would put inferior material into a boiler, merely to save first cost, did not deserve to have anything to do with boilers. But, as he had stated, there was, he believed, no question as to the sufficiency or efficiency of iron for shipbuilding. One point in the manufacture of steel plates had not been sufficiently considered, he thought. He was not able to give it a scientific definition, and he would therefore call it by the old name known to mill managers—work. There must be upon steel, as upon iron, a large amount of mechanical compression, which they called work, before good sound plates could be produced. He did not know much about the cause of the recent notable failure of plates in a celebrated ship, but while in Scotland recently he got some information about it. He found that the plates were unusually thick and behaved very badly, notwithstanding that, chemically, there was not much to complain of. He was convinced that insufficiency of work was the cause of their failure. The necessary work was somewhat difficult to get. Let them consider a rail, say, of the usual 80-pound double-headed section. It had 8 inches of cross-section and was made from an ingot about 15 inches square. In this case the end section of the ingot was twenty-eight times that of the rail. But when they came to plates, no such relation of ingot to the finished article was practicable by means of any appliances he had ever seen. Supposing a plate half an inch thick and 50 inches wide to have on it work in proportion to that on the rail referred to, they would want an ingot 35 inches by 20 inches thick, a most unwieldy thing to deal with. If the plate required were an inch thick, the same ratio of ingot to plate would be 40 inches wide by 35 inches thick. He did not know any plate-making machinery that could deal with such masses of steel, and he believed that at present they could not put upon plates by rolling the great amount of work that was given to rails with excellent results. He was not at all saying that the present state of the plate manufacture must continue; on the contrary, he thought that the day would come when there would be great economy and improvement. At present, that which they could not get by rolling was obtained by hammering and other expensive operations that added seriously to the cost of plates. He remembered, a long time ago, Sir Henry Bessemer propounding a mode of making plates from fluid steel fed into rolls 40 or 50 feet diameter from a hopper. If this could be accomplished, endless plates would be produced; but he feared that, unlike some other prognostications of Sir Henry which had been fulfilled, this would not be found practicable. But steel plates could and would, he believed, be made, not as cheaply as iron, but much nearer the iron price than at present. He had not had much to do with making steel plates, but he was an old iron platemaker and so ventured an opinion. The new systems of testing had added much to the cost of steel, and anything that could be done in the direction of removing needless worry and risk from the makers would certainly be advantageous to all concerned. As he had said, he thought Mr. Denny, whom they all knew and greatly respected both for his business skill and general character, had been hard on the platemakers, inasmuch as he had come to the opinion that they were not skilled in their business, and not desirous to help the much-to-be-desired improvement of their products. The very contrary was the fact, and he was sure that makers generally, whether of iron or steel, were most anxious to produce plates of the best quality and at the lowest possible price.

Mr. JAMES RILEY (Steel Company of Scotland) said he had prepared himself for that meeting, not knowing whether Mr. Parker would give them any adverse facts with regard to the use of steel in boilers. It was certainly alarming to peruse the paper that had been read in that room some few weeks ago. At that time, he had taken occasion to send round to the various firms to whom his company had supplied plates, and he had asked them what their experience was as to steel boilers, and their testimony was particularly confirmatory of the closing remarks of Mr. Parker, that there was no difference between the action of their boilers of steel and of iron, in so far as corrosion was concerned. Whilst sympathizing with the remarks of the last speaker, he did not think it was the intention of Mr. Denny to be particularly hard on the makers of plates. Personally, he should express his thanks to Mr. Denny for his paper; for he had given them information which he had been searching for for a very long time, and which he had not been able to get hold of elsewhere in so concise a form. Because of the manner in which Mr. Denny and other enterprising firms on the Clyde and elsewhere had taken up steel shipbuilding, the position of the makers of steel plates had been much lightened. Steelmakers had had difficulties, and they had overcome a great number of them; but it was owing to the assistance of gentlemen like Mr. Denny, and there were many of them, who had helped them constantly, and therefore he accepted in all good faith what Mr. Denny had said, and he would tell them, whatever might have been said by the last speaker and others, that there was as strong a desire on the part of makers as there was on the part of Mr. Denny to make steel plates as cheap and as good as they possibly could. He hoped that all present had determined that they would never sacrifice quality to cheapness. If there was any intention on their part to do that, there were certain gentlemen sitting near him who would take care that they did not do so, so far as they were concerned. A good deal had been said about societies and testing. Personally, he had no desire to get rid of testing. Individually, if Lloyds, the Board of Trade, and other societies thought proper to relinquish the strictness of their tests, they might do so; but he would not wish it to be relinquished, for if they departed from the tests they would get into serious difficulties, and the reputation which they had striven hard to earn would soon be lost. Steelmakers should not be pilloried because they had on some occasions happened to let a bad plate go out; and yet he must say that there was a desire on the part of some of their friends to put them in the pillory for any slight mistake. There seemed to be an extreme desire to get hold of the slightest failure of steel and make grand diagrams and write papers about them, in fact, to crucify them. Although he had not gone through as much as some of his friends, still he felt strongly about the matter. After all the care they took with their productions, it was unfair that there should be such a searching out for defects, and that the successful work that they accomplished should be ignored.

Sir Henry Bessemer said he was very much gratified at having heard the paper just read by Mr. Parker. Some six weeks ago he had heard a paper read in that room, and the subject was then treated very differently indeed. He had taken the trouble to work out some of the results that were to be inferred from the statements put forth by the person who read the paper on that occasion, and who gave them numerous figures. The corrosion, according to his experiments, came to this: A boiler made of $\frac{3}{8}$-inch plate would lose so many grains per inch per week, and at the end of $8\frac{1}{2}$ years there would remain only the coat of paint on the outside, and not one single grain of metal would be left after that period. So alarming a result led him to inquire whether there was any evidence tending to prove such a statement, and whether boilers in use something longer than that period still existed as a fact and not as the ghost of a boiler. Under these circumstances there was just time for him to send a telegram to his friend Mr. Richardson, whom he saw now sitting near him, and who had great works under his charge, for he was connected with Messrs. Platt Brothers, of Oldham. That gentleman had been so well satisfied with certain trials made with steel for boilers, that he determined not to make a little trumpery experiment, but a practical test with no less than fifty tons of steel plates, by making six boilers, 30 feet in length by 6 feet 6 inches in diameter, with flues 3 feet 10 inches running through, and with a thickness of metal not exceeding five-sixteenths of an inch. From the period at which these boilers were set to work it was now within a few weeks of twenty-two years, and this might be considered as something like a practical proof of the durability of steel for boilers. Well, as he had said, he telegraphed to his friend Mr. Richardson asking what state the six boilers were in, if they still existed, and his friend replied that "they had all the six at work, and they were still most satisfactory, showing no signs of corrosion." He thought that such evidence was a full confirmation of the statement that the corrosion of steel was no more than that of iron, and the instance given might be taken as a convincing proof of that fact.

Mr. PARKER, in reply, said he had very little to say in answer to the remarks on his paper. All the speakers seem to corroborate the views he expressed, namely, that so far as experience had gone, mild steel did not corrode to any serious extent more rapidly than iron under similar conditions. He was glad to hear from Mr. White that it was not merely a matter of *belief* with Mr. Barnaby, but an ascertained fact, that a strong galvanic action goes on between the scale and the patches of bare steel. Mr. Williams and Mr. Riley had made some observations on a subject apart from the paper, which he could not allow to pass without a few remarks. He gathered that Mr. Williams was of opinion that a certain amount of mechanical work must be put on the ingot before a plate can be produced to stand all the tests and work satisfactorily. Now, it happened to be Mr. Parker's duty to investigate the cause of the failure of the steel plates referred to by Mr. Williams, namely, those used in the first boilers that were made for the Czar's yacht *Livadia*, and it might be interesting if he briefly summarized the main points. The plates, which were three-quarters of an inch thick, were, in the first instance, tested at the works of the makers with apparently satisfactory results, the tensile strength being 26 to 28 tons to the square inch, and the elongation 34 to 27 per cent. in a length of 8 inches. At the yard of Messrs. Elder, the plates were punched and the holes afterwards rimmed. One of the plates fell from the slings when being carried across the yard, and on examination a number of the rivet holes and the edges of this plate were found to be starred and cracked. The makers were then sent for, and they informed the builders that the punching had destroyed the material, and recommended annealing to restore the normal condition. Accordingly, all the plates were sent back to the makers, where they were annealed. On being returned, they were riveted up in their places in the boilers without further mishap, and it was not till one of the boilers was under hydraulic test—before the proof strain had been reached—that two of the plates cracked along the line of rivet holes. Further examination showed that a similar crack of less extent existed in another of the boilers which had not been subjected to water pressure. Pieces of the injured plates were found to be so brittle that a light blow from a hammer broke them into three or four pieces. When a specimen of this quality was annealed it bent almost double, and also when the injured edges of the strips were planed, or the rivet holes rimmed out, the material stood bending perfectly well. Again, when additional work was put on to the material—the original thickness being rolled down to one-half, namely, three-eighths of an inch—the samples, although, as was to be expected, increased in tenacity, were as ductile as the annealed samples. By this means, also, the fractures, which in the original samples presented a peculiar striated appearance with signs of lamination, assumed the silky fibrous texture of good steel. In fact, the material had undergone a radical change, as would be seen by the specimens produced at the meeting. This was decidedly strange behavior, and quite different from what they had previously experienced in mild steel. It had been said that every slight failure in steel was heralded forth, while the many failures in iron were allowed to remain in obscurity; but they must remember that there was very little analogy between the failures to which they were accustomed in iron and those which were now and again being brought to light in steel. The cause of the failures of iron was self-evident, while steel was very capricious in the way of its failures, which so far had not been readily grouped under any intelligible law. The plates to which he referred, for instance, broke without being touched, but they never found iron behave so under similar treatment.

The president proposed a vote of thanks to Mr. Parker for his admirable paper. That gentleman had introduced a subject which was most interesting, because of the celebrated paper which had been read some weeks previously, and which had caused so much anxiety to persons manufacturing steel plates. He thought they would also agree with him, as to Mr. Denny's paper, when he said that they had never had a paper dealing so candidly with and giving so much insight into the manufacture of steel vessels. He was sure when that paper appeared in the archives of the institute it would be studied again and again by everybody engaged in shipbuilding, and every time they read it they would derive some information. As they had taken the papers together, it would be desirable to have a vote of thanks to Mr. Parker and to Mr. Denny taken together also.

The vote of thanks was accorded by acclamation.

ON CRACKS AND ANNEALING OF STEEL.

By A. C. Kirk, Esq., *Member of Council.*

[Read at the twenty-third session of the Institution of Naval Architects, 30th March 1882; the Right Hon. the Earl of Ravensworth, president, in the chair.]

It is well known that occasionally steel plates have been cracked in a way very mysterious and unaccountable, and the general cause to which it has been attributed was want of annealing, or that process done badly. But, whichever was the way, it has been commonly assumed that the cause is the existence of unequal strains in the plate produced by unequal cooling.

To confine this mystery to narrower limits, and elucidate the question of annealing, is the object of this short paper.

About the middle of June, last year, I had my first experience of these cracks that it has ever been my good or bad luck to have happened actually in my own practice.

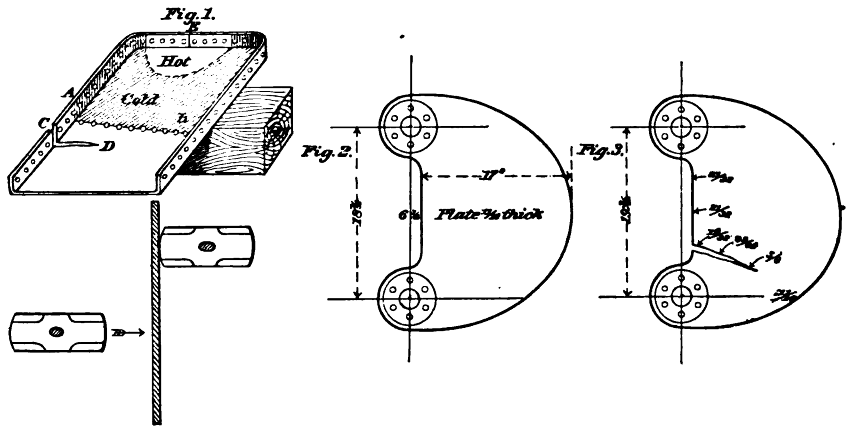
The plate (a back tube plate) had been flanged at the smith's fire, heated all over in the furnace, straightened up, and allowed to cool in the usual way.

The centers of the tube holes were marked off for boring, and two men were deepening the centers for the boring machine with a flogging hammer and punch, when the plate cracked, as shown at C D in the appended sketch, Fig. 1, from which you will see that when it cracked the plate opened at C, showing that there was a strain at that point on the plate. The plate simply cracked, and was not in the least reduced in thickness on either side of the crack, showing that no extension previous to fracture took place, in this respect agreeing with all the best information I have been able to collect of similar fractures which have occurred elsewhere.

With regard to such cracks, it has long been my opinion that it is hard to see how a material which can stretch 25 per cent. under a strain without fracture can break with no extension at all. This is confirmed by many things we see often; notably so in steel rivets shrinking and never breaking, flanged boiler fronts, with holes flanged in them, which have been heated and worked piecemeal, and which I have never found to crack, though tumbled freely about before they were put in the furnace and straightened, that is, virtually annealed.

From this we may deduce that, when such fractures occur, there is a presumption that there has been from the beginning—from the ingot state, probably—a line of weakness, along which the fracture takes place. As this seemed worth testing, I set about it as follows:

I had the plate drilled across at the line A B, shown on Fig. 1. The remainder of the plate I had heated in the furnace all over to a bright red, removed, and laid outside, as in Fig. 1, and cold water and wet cloths applied to the shaded part, marked "cold," till it was quite cold. At this time the unshaded part, marked "hot," was hot enough to just set fire to straw. The whole plate was now cooled as quickly as possible.



Thus, I think, I succeeded in putting the upper part of the plate in tension to the utmost degree possible by unequal cooling, and if steel must break when that is done, it ought to have cracked in the flange marked "hot." Lying on a block of wood, I had it struck six times over various parts of its surface, by full blows of a 28-pound hammer, which produced no effect. I then had a 28-pound hammer held up against the flange at one side and struck four times with another, the only result being to bend the flange slightly. The same thing was repeated in the middle of the flange, at the "hot" end, with the same result.

I then had the flange at hot end at E, Fig. 1, nicked deeply on edge and both sides with a rod chisel and 28-pound hammer; after which the plate was struck six blows on the surface without fracture. After that the flange was held upon one side of the nick by the same hammer and struck four times on the other side, without starting a fracture. I then had it next supported on two blocks under the steam-hammer about six inches apart, and bent the part between these three inches, still without producing a fracture.

Thus, sound steel put intentionally into the greatest state of tension possible, by unequal cooling, does not crack, and cannot be cracked.

I have heard the proposition stated, I believe, in this room, by an eminent steel-maker, that contraction tears a plate, the fracture then commencing at the edge and gradually extending into the plate, and that thus you could not expect to have extension as in a simultaneous fracture right across a piece of steel.

I now lay before you the result of having a piece of steel plate torn in this way, and the result will completely dispel any such illusion.

The plate I prepared was of mild steel, shaped as in appended sketch, Fig. 2, with the object of tearing it by direct tensile strain. The results obtained were quite in accordance with my expectations, the thicknesses decreasing in all directions towards the place of fracture, but more especially along the edge of the plate and of the fracture, as will be seen on reference to appended sketch, Fig. 3.

The plate stretched between centers 1½ inches when rupture took place under a load of 80 tons. The action of stress throughout the material is distinctly marked in clearly defined lines, by the cracking of the surface skin or scale.

The experiment was carried out at Lloyds' testing house, and, owing to the arrangements in their chain cable testing machine, one end only could be fixed to the machine head, while the other had to be fastened by a shackle to a cable end.

This, I take it, proves that the tearing theory—which, I confess, I never could comprehend—is no explanation; and, further, that such cracks are simply due to lines of weakness in the steel, which annealing will not cure, although it may easily, as I showed in the discussion of the steel of the *Livadia's* boilers (vol. xxii, page 25), do harm; and that the best thing is a certain amount of rough treatment (even if done intentionally as a test), and if that cracks a plate the plate is to be thankfully rejected.

I hold that I have succeeded in proving that these mysterious cracks in steel are not produced in the working of the steel after it is rolled, and when the germ exists they cannot be prevented from showing themselves by annealing; the only test being some rough usage and knocking about. It remains for the steel-maker to assign a cause for these fracture lines, and provide a remedy. After all, we have much fewer defects in steel than we had in iron, although, it is true, they are of a different kind.

DISCUSSION.

Dr. SIEMENS. My lord, the author of the paper alludes to a discussion which took place in this room last year, and I almost think that he must have alluded to something which fell from me with regard to the tearing of steel plates. If that is so, I should like to explain in what respect his view of my remarks differs from what I intended to convey, and why, from the very experiments which have been placed before us to-night, I am rather confirmed than otherwise in my view. Steel, as the author of the paper very correctly shows, does not give way partially if it is subjected to fair strains. Even if it is heated unequally and the strain is put upon it, it will yield gradually to that strain and will not break; but, on looking at the diagram Fig. 3, what do we see? Surely not a break due to dead tensile strain, but a tear. There has been some time occupied when the pressure gradually was brought to bear on those two points, when the edge of the plate, being perfectly sound, yielded as a whole to that strain. But when at any point on that surface a slight defect, probably a sharp notch produced by the cutter employed in planing that edge, when that one point was strained to the ultimate point of fracture, then the plate gave way there, and a tear arose—a tear that did not follow the laws of gradual extension and ultimate fracture, but one that from the point of disseverance went forward, without previous extension, of those other portions of the plate before they gave way. The extension between point and point in Fig. 3 affected only the metal immediately between the points of force. But if the line was drawn or a cut was made through the disk halfway down to the bottom, you would have all the conditions of a mere tear, or no extension but rupture. And thus I maintain that when steel plates have given way in what is called a mysterious manner, it has always been due to an incipient disrupture somewhere. If the plate is supported on one pin, for instance, and the whole of that on which it is supported has been a rough punched hole, then the moment the strain comes on a tear will set up and run along the plate, not across the section, but according to the fancy of the crack, in the same way as if *this* was India rubber, and I brought upon it an equal strain, I would extend the whole band of India rubber. Suppose this is a band of India rubber, with the edges intact; I could stretch this to perhaps four or five times its length, and it would come back to its original length; but if I took a pair of scissors or a knife and just nicked the edge and tried the experiment again, it would tear across here before the mass of India rubber had been extended to any great extent; and I believe that is the real explanation of all these so-called mysterious breaks in steel plates.

Mr. JOHN. My lord, I should like to make an observation or two upon Mr. Kirk's paper and upon the remarks made by Dr. Siemens upon it. I should like to say this, there is an essential and a very important point at issue beteen Mr. Kirk and Dr. Siemens, far more than the explanation of a crack. It means this, that there have been certain cracks, certain mysterious, as we consider them, fractures, in steel plates, which Dr. Siemens explains in the way you have heard him to-night, which Mr. Kirk and many of us do not agree with, and which Mr. Kirk has been testing, and except for one little point he has cleared the matter up. The one little point which appears to have been wanting in Mr. Kirk's experiments is that he did not try nicking one of those plates just at the point where he began to tear it, and then seeing whether it was going without stretching, as Dr. Siemens said it would. The real question at issue is this, whether these mysterious fractures that have taken place are due to radically bad steel, or are due to the possibility of good steel behaving in this way. My impression, after many experiments, and after a good deal of thinking about the matter, is that they are due to radically bad steel. In all these mysterious fractures that we have had the steel has not been right, and many of the plates I have seen tested that have fractured, if they had been submitted to anything like the heating process that Mr. Kirk applied to that plate, would have flown into a thousand pieces under that treatment. I will give you an illustration from a plate I saw tested in Mr. Denny's yard, one of those plates that was fractured. Mr. Parker and I were there.

Mr. PARKER. That was quite an exceptional case.

Mr. JOHN. It is not exceptional, it is the question of bad steel. It was a plate that was cracked. A piece was cut out of it; we knew what was going to happen; we had a long strip of it cut; we said to Mr. Denny's manager, "Now strike it." He struck it, and it flew into two pieces. "Now," we said, "we will make it tough for you; plane down the two edges one-eighth of an inch off each edge; now bend it." It bent double. "Now," we said, "we will make it brittle again; punch a hole in it; now strike it." It flew in pieces again. Now, if that plate Mr. Kirk had been testing had been anything like that plate it would never have stood that treatment. I do not know the explanation, and we have to look to the steel-makers to give the explanation why those plates were in that condition. It is an absolute fact that with plates, after certain treatment if you nurse them up and plane the edges and remove the damage from punching, the plates would double up right over, but the moment you put rough treatment on them they were as treacherous as plates could be, and not fit to go into a ship or boiler. The chemical constituents of those plates were tested in various ways; nobody could find out, and nobody to this day has explained it, and I cannot accept Dr. Siemens's explanation to-night as putting an end to or giving us a solution of the matter.

Mr. W. DENNY. My lord, Mr. John has referred to experiments made in our yard. I remember perfectly the subject he mentions and the plates in question. On one of these plates, a garboard strake plate, we let a very heavy weight fall from a height of thirty feet, and the result was that the plate splintered. We got a splinter out of the center of that plate (Mr. Martell will remember; he was present), and it was exactly like pot-metal; but we planed the edges, and, curiously enough, the last stroke of the planing machine lifted the little piece of steel that was left like a feather in a curl right around. We took the planed portion and bent it double. I most thoroughly agree with Mr. John that where such inexplicable facts occur it is evident that the material is bad, and there is nothing for the ship-builder to do but to condemn it, and to define clearly the conditions of the case, so that they may be well investigated. Mr. Kirk, in the final part of his paper, makes a remark which might have been deduced from the facts mentioned by Mr. John, and the evidence which has been gathered by my own firm. He says, "The only test is some rough usage and knocking about." The treatment of steel resolves itself into that. I think my firm have used more steel than any other shipbuilding firm in the country, and every day we have come more and more to the conclusion that the fewer the precautions the better, because the fewer the precautions the more likely we are to discover defective materials; and I am happy to say in that policy we have been fully backed up by Lloyds', who have thrown over many frivolous precautions with which they started, precautions which really damaged the cause of steel because they nursed defective material. We are now treating steel roughly, and any steel which does not stand that treatment is thrown on one side. Dr. Siemens's explanation of the whole matter is extremely ingenious; but this meeting should not forget that Mr. Kirk has pointed out a radical difference between these two cracks, explain it how you like. In the case of the cracked C D, there is no dimunition whatever of the section. In the case of the crack shown in the test piece there is a diminution, however slight it may be. I think this simple fact makes the difference between the good steel and the bad.

Dr. SIEMENS. No, certainly.

Mr. PARKER. Certainly not.

Mr. JOHN. It is very easily tested.

Mr. W. DENNY. I am willing to be corrected. There is one point I wish to draw the attention of the meeting to with regard to these experiments, and that is this: in the same steel plate it is quite possible to have both good and bad. In this plate which Mr. Kirk tested we have the crack C D, but we have also the nick E, which was tortured and tested, but it did not fail.

Mr. PARKER. In what way tortured?

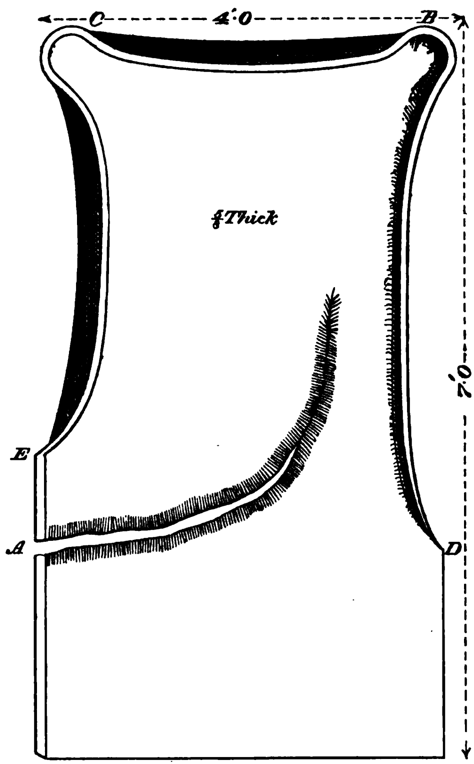
Mr. W. DENNY. We have Mr. Kirk, who tells us distinctly what torture was put on it. He tells us he hammered it and twisted it about, and it did not give way.

DR. SIEMENS. I would like to say one word, my lord, in explanation. I thoroughly agree with almost everything these gentlemen have said, and if I still maintain that it is from the cracks or from the want of continuity in any one point that the tearing action sets up, I do not for a moment wish to say that that was a good plate. That plate had an incipient crack in it; probably it had been rolled from an ingot, and in rolling it up there had been a very slight crack. That is a very different thing from a nick, and the beginning of a crack is already a tearing, and whenever the least tearing action has set in then the tear will go on from that point, without elongating the whole metal. I did not mean to say that that plate had not a fault in it—I am convinced it had a fault, but I wished to draw a distinct line between breaking a piece of steel and tearing it.

Mr. W. DENNY. Will you permit me a word of explanation? It is simply this, that in the plates we dealt with—the defective steel plates—Dr. Seimens's explanation could not have held good, because we could develop cracks in any direction.

Mr. D'A. SAMUDA. I should probably not occupy the time of the meeting, because I do not attempt to explain what may be the mysterious circumstances which have produced this result; but what I do wish to do is to protest against conclusions such as have been expressed by Mr. John and Mr. Denny taking the place of such investigation as ought to be made to come to the bottom of these circumstances. Now, I would say that one matter within my own knowledge has been left out of consideration in this altogether. I have seen steel plates in my own yard over and over again that have performed all these antics which have been described by Mr. John and Mr. Denny as being radically bad plates, and better plates never existed. The only explanation that I have been able to give to it—and I do not attempt to give it as a satisfactory one—is that at a certain temperature the steel has one set of qualities, and at another temperature it has a totally different set of qualities. I have seen a plate in my own yard, and in my own presence, when it has been attempted to put it under the temper test at the time when it has got to a black red, being so perfectly bad to all appearance that the slightest blow of the hammer would produce a crack and break that plate, and yet if you carried through the whole of the experiments with that plate, or if you allowed that plate after it has really been broken at this temperature to remain until it was cold, a better plate has never been shown, and it was as good as any plate that has ever been manufactured. I do think when such circumstances as these exist, which every practical man must see, and when neither one nor other of those gentlemen more than myself are capable of telling this meeting what has been the cause of the extraordinary action of the steel which they have condemned so frankly, they should be a little more careful before they condemn plates, and should look a little more to the circumstances of the case. The fact is, that this steel I have referred to, which had exactly the action upon it which they have described, and which they have described as being nothing more than bad steel, has really been the best steel that could possibly be produced. I will leave it to Dr. Siemens and those who know better than myself to explain how that is caused, and how they can vary that and prevent it; but that that steel was good there can be no doubt, and that steel is in my possession now, because I took care of it as being one of the most extraordinary things I had ever seen. I saw it broken with such a tap that no piece of common iron would have broken with, and yet it was perfect, and as capable of performing all its functions as the very best steel that has ever been put in any ship.

Mr. PARKER. My lord, this question of what are termed mysterious fractures and cracks in steel plates has been discussed on several occasions at this Institution, and there remains little that is new to be said. For my own part, I feel some diffidence in going over ground that has been so often traversed both here and at kindred institutions, and I am also reluctant to say anything in disparagement of what Mr. Kirk has put before us, as he is not here to defend his position; but at the same time I feel bound to say that I entirely disagree with Mr. Kirk in the conclusions he has arrived at in the paper we have just listened to. I am more inclined to attribute the failure of the plates referred to by Mr. Kirk to the cause which Dr. Siemens has so clearly explained. It seems to me that in connection with this matter we must be careful to distinguish between the *cracking* of a plate and the *tearing* of a plate—two decidedly different things. Any steel plate which is found to crack must undoubtedly be brittle, but we may have, as indeed we have had, steel plates of unquestionably good quality tear or rupture, owing to the great initial stresses set up by local heating, which stresses, when concentrated at any particular point of the plates, must find relief by the tearing of the metal. The cases Mr. John has referred to were quite exceptional. They are the only two instances that have come under my notice where really brittle steel has been found, out of all the material we have used, and over forty thousand tons of steel plates were used last year for shipbuilding and marine boiler-making. The first case was that of the plates supplied for the shells of the *Livadia's* boilers, which I had the privilege to investigate, and which I endeavored to explain in a paper read here last year; the other case happened with some ship-steel supplied to Mr. Denny's firm. In both of these instances the steel was brittle and of inferior quality, there could be no mistake about that, but the cracks found in those plates were of a different nature from the ruptures produced in Mr. Kirk's specimens. The inferiority of the material was traced—I cannot say conclusively traced, but to a great extent it was traced—to the absence of a sufficient amount of work on the ingot or slab before it was rolled into a plate. I think it is an acknowledged fact that if you take a piece of steel from an ingot, I mean ordinary mild steel such as plates are made from, and do not put any work on it, or pass it through any other process, you will have a somewhat brittle material, while if you hammer or cog or otherwise work that material, you will render the plate more ductile. It would appear that there is still some difference of opinion as to the absolute amount of work required to produce a plate capable of withstanding all the accepted tests. Mr. Webb, of Crewe, who has a large experience in the matter, says that no ingot should be less than twenty times the thickness of the plate to be produced from it, whilst others, again, do not attach so much importance to that point. Be that as it may, however, the failures mentioned by Mr. John were decidedly unique, and have no parallel in all our experience, nor can they be placed in the same category as the results of Mr. Kirk's tests. You will observe that the tearing mentioned by Mr. Kirk has occurred in plates that were locally heated, and, as I have already stated, this will, in my opinion, account for the results. As an illustration of the effect of local heating in steel, I will take one of many cases that have come under my notice. The sketch which I make represents a partially flanged back tube plate for a marine boiler. The flanges were about 6 inches deep, and the flanging was done in the ordinary way in short lengths of about 9 inches, being commenced at the corner, B, and proceeding to C, then from B down to the point D, and then on the opposite side to the point E. The workmen had just finished the heat ending at this point and left the plate to cool, and upon



their return they found the plate torn from the point A in the direction shown on the sketch. The tear had opened $\frac{3}{16}$ths of an inch, and the material along the edge was reduced in thickness, indicating considerable elongation before rupture, while even beyond the end of the tear the metal was appreciably thinner. Now, according to what we have heard to-night, this plate must have been of bad quality, but we found it possessed of the prescribed tenacity and elongation, and chemical analysis showed nothing abnormal in its composition. In fact, the plate was as good as a plate need be, and yet it tore in this manner. And why? Simply because it had been improperly worked. The expansion and contraction of small patches of the plate caused by the repeated local heatings and coolings induced strains in the material which, culminating in the contraction of the flange ending at the point E, relieved themselves by the rupture commencing at the point A, where there was a slight nick or inequality in the edge. This is but one of several cases where the failure of steel plates in this manner has been traced conclusively not to inferior material, but to improper manipulation. Such cases were not unfrequent in the early days of steel, but the cause, namely, local heating, having been discovered, is now provided against, and we hear nothing of similar failures. I may add that these so-called mysterious fractures of steel plates have not in any way discouraged the users of steel, who are now more numerous than ever, and still on the increase. With a fuller knowledge of the qualities of the material many misgivings have disappeared, and while we may not yet have fathomed all its secrets, we are able to avoid many of the failures which marked its first steps, and to work it practically with entire success.

Mr. THORNYCROFT. Having had a considerable experience with steel I would like to make a few remarks upon it. I do not feel anxious to nurse bad steel, but I rather think that the workmen consider by working it warm and not cold they can nurse it. That is a great mistake, and I quite agree with what Mr. Samuda has said, that temperature is a great explanation for the behavior of steel with regard to what has been called cracking. I thoroughly agree with what Dr. Siemens has said and his theory as to the manner in which these cracks may be produced, and may proceed from one part of the plate to the other without to any considerable extent stretching the edges. What I mean is that a piece of thoroughly good steel may crack in a way that would make one believe it was really bad steel, and, further, that a crack may be initiated by working the plate at a temperature between cold and red heat—what is known as black heat—something above blue heat. When steel is heated to a particular temperature it forms an oxide and appears blue, and I think a little above that temperature most steel is very brittle, although it is good. I thoroughly agree with what Mr. Denny has said—that steel should stand rough usage; but what I also know is this, that a piece of steel that has cracked and appears unsound altogether, may, when worked cold and used roughly, prove to be a good piece of steel. In our works we have had plates broken, and have thought them bad plates, but we have found that the workmen, in order to work those plates and in order, as they imagined, to give those plates a better chance of bending, have heated those plates or worked them before they were thoroughly cold, and in that way they have initiated a small surface crack which has afterwards caused the plates to break through and appear bad. Now, we have taken a piece of the plate from the neighborhood of the crack without any special planing—the plate has been hammered over the anvil cold with a comparatively rough edge, and has been very tough. But I think still there is this, that the very perfection of steel, the uniformity of its structure, is a source of weakness in the material. Very perfect steel is almost uniform in structure, like a gum resin. If you take pitch and pull it gently you may extend it to any form you wish, but if there is the least suddenness of strain, although it is elastic, the continuity of its structure causes the stress when a crack is once started to come upon a very few particles at once, and you get one portion of the mass sustaining no weight, the portion away from the crack stretching to some considerable extent. Near the end of the crack you get some particles which are so near to the part that is doing no work that they have too much work thrown on them, and these particular particles give way one at a time, and the continuity of the steel is a source of weakness when a crack is once initiated. If you examine the structure of a piece of iron, which is considered less perfect than steel, it consists of a mass of more or less tough material separated by atoms of impurity, and these divide it and perform the functions of a drill-hole at the end of the crack. Suppose you proceed to break a bar asunder, it breaks through until you come to a little lamina of dirt, and there, instead of the strain being thrown on one little particle, you get it thrown on particles where it will extend, and there the crack ceases, just as in the case of the drill-hole which workmen put at the end of a crack to prevent it extending. To sum up, I say that steel should bear rough usage. I think some steel is more liable than others to be cracked. I think steel should elongate to a considerable extent before breaking under a tensile test. It is also satisfactory to find that a low strength given to steel sometimes, in order to insure this, does not always have the desired effect, and we may hope to get steel of a greater strength having reliable qualities.

Mr. MARTELL. I fear the effect of this discussion will be to cause many to have less confidence in steel than they have had hitherto. ("No, no.") It is all very well to say "No, no." All the arguments that I have heard adduced here have been to show there are still mysterious cracks in steel, call them whichever you like, cracks or mysterious tears. Mr. Samuda says it plays up fantastic tricks. We know nothing about fantastic tricks in iron—such as cracking without assignable cause—and if these fantastic tricks occur in steel it must certainly tend to decrease confidence in a material of that kind. Now, I do not believe in that at all. I differ altogether with regard to the mysteries that are said to exist in this material, and for this reason, that I have been called in to examine many cases of this kind where the said mysteries have occurred, and in all the instances I may say I scarcely know one where failures have occurred where we have been unable to find out how those peculiarities originated. I remember an instance where, in a ship building for a well-known company under our surveyors, a large number of plates failed. I was called upon to investigate this, seeing it was a very important matter. I did so in conjunction with my friend Mr. Denny, and I believe the result of that investigation was perfectly satisfactory, and we found out the cause of that failure. Had it been thoroughly reliable material, as it should have been before being sent from the steel works, it never would have shown up the tricks it did in that case; and I do not believe that good steel, which we know can be produced, will exhibit these extraordinary symptoms. I have never found in all the cases that I have seen these mysteries occur in good steel. I believe this, that when steel cracks we should throw the responsibility upon steel manufacturers, because I am persuaded, from the thousands of tons of steel which have been inspected in the steel ships which are now afloat, and which have been running and encountering rocks and coming in collision in various ways, we have not found any mysterious cracks in any of them up to the present time. I believe that all steel should be capable of undergoing the amount of hard work which Mr. Kirk suggests, in order to find out whether it is a fit and proper material for shipbuilding purposes; and I do think the nursing that has been spoken to by Mr. Denny, more particularly with regard to the French builders in using wooden hammers, &c., prevented us knowing the nature of this material a great deal more than we should have done if it had been used as we require in the same way as iron. Mild steel, in my opinion, should be used in the same ordinary way as iron is used in a ship-yard, and if it cannot stand that hard usuage it is unfit for shipbuilding purposes. I would wish strongly to put that forward. It should be used in the same way and subjected to all the hammering that iron is subjected to, and if it cannot stand that, then it is not fit to go into a ship-yard and not fit for shipbuilding purposes. I go further, because I believe that good steel will stand this treatment, and from anything I have seen with regard to the difference in the heating of steel and the stress that is brought upon it in different parts, I do not think it will have any effect in causing cracks in mild steel if it is of a good quality, and when these cracks occur it is inferior material and unfit for the purpose for which it was intended.

Mr. PARKER. Still it stands all our tests.

Mr. MARTELL. When it stands all the tests, I want to see the mysteries alluded to in connection with such steel. I have not seen it. Why do not we see that mystery in the many ships which are already built? I would like to see a specimen of the steel Mr. Samuda has alluded to, which has exhibited this extraordinary character, and is said to be yet good steel. I venture most respectfully to express my doubt whether it is good steel; I think it is radically bad steel. If it exhibited those qualities it ought to have been condemned right out, as, though you may be able by manipulation to make the very worst steel bend double and go through all these fantastic tricks that you have heard spoken about, it is, in my opinion, radically bad steel at the bottom; and if it shows any symptoms of cracking, no matter what the circumstances may be, it should be condemned offhand at once as being unreliable; that is my opinion of it. I think, with Mr. Kirk, that the principal part of these failures are really due to original defects in the original quality of the steel itself, which manufacturers should take care to have uniform before sending from their works.

Mr. W. H. WHITE. Will you permit me just one word? I will not detain you, but we have, my lord, as the meeting may not be aware, the advantage of the presence here this evening of Mons. De Bussy, who, in the French dockyards, was the first to introduce and work steel, and without entering into any controversy with Mr. Martell, I may be permitted to say, as one who from the very first in England has had to do with steel, that we cannot be too grateful for what the French did in making and introducing mild steel. We may say what we like about nursing, I say that the French builders in the introduction of steel displayed a very wise discretion, and if we have reaped the advantage of their efforts, do not let us forget it. Do not let us talk at this time of day, seven years after the admiralty began to use steel, as if we had not learnt anything in seven years. We have. We are constantly learning, and we should be the worst description of people—I will not say, in short, what I think—if we did not admit that we had been learning. We know this, and Mons. De Bussy will confirm me, when I say that in the French dockyards their practice has been largely modified as years have gone by, and they have grown to know more what steel is. Do not let us go back on the historical side, and say that nursing was wrong when it was practiced; I do not believe it. Do not let us say that because rough usage is a good test, that, therefore, scientific tests are absurd; I do not believe it. It is necessary for strictly scientific purposes to prepare samples in a strictly accurate manner. It is also necessary, in order to get the material that should be used in either ships or boilers, to subject it to rough usage. Do not let us have one view of the case put to the exclusion entirely of the other. The thing is absurd. We are practical men, and base our practice on scientific experiments and inquiries. I have said a good deal to you about the French, and I am quite sure that Mons. De Bussy will excuse my allusion to him. Members have only to turn to the Transactions of last year to see that they do not in the French dockyards now nurse steel, but they work it as others do. Now I want to mention another point or two. The discussion, if I may be permitted to say so—for I listened without the least intention of saying a word—has been rather discursive. There are two points upon which there is practically agreement, and they are the two most important points for our purpose. We have Mr. Kirk and Dr. Siemens agreeing entirely that in this plate which failed there was probably an original defect. Let us recognize that; there is an agreement on that important matter. There may have been, although it would seem an extraordinary thing that the defect did not declare itself sooner, an original defect. We also have it agreed that there is good steel and there is bad steel. But the bad steel, as far as my experience goes, is not to be compared in its properties to the bad iron. There is good and bad iron. The bad steel, in proportion to the good, is not to be compared with the bad iron in proportion to the good iron, that is, as to the probabilities of the material. Mr. Martell has said that iron did not play fantastic tricks. Mr. Thornycroft has given us an explanation, which we have heard before. It did to the utmost of its ability; but, poor thing! it could not go so far as steel did, because of its very imperfection of quality. Let me explain what I mean by an example. Mr. Samuda has very properly drawn attention to the fact that in mild steel there is a temperature where it is more likely to fail than at other temperatures. That is true of all malleable metals, and is not peculiar to mild steel only. There is a temperature where even with an increased tensile strength there may be less ductility and inferior working qualities. I say that is not peculiar to steel alone. In steel there is the blue heat or black heat, about the temperature of molten tallow, where there is undoubtedly a great tendency to failure—just that which Mr. Samuda described, but that was an extreme case. But is that peculiar to steel? Well, iron had a wonderful deal credited to it without investigation—it was treated charitably, but we have endeavored to find out, as we have been looking so closely into steel, whether iron did not behave something in the same way at the same temperature, and as the result of a great number of experiments made on a great number of makes of iron and steel (and there will be put before the Institution tables in support of the statement), iron does behave, at a temperature not dissimilar to that which we call the blue heat for steel, in a way not very different from the way in which steel behaves. The only thing is that the character of the fracture is different in the two metals. In the steel the fracture, owing to its structure, goes through the thickness; in the iron, as Mr. Thornycroft said, the cinder, or the impurity, forms a stop to the fracture. You get a breakage through a certain distance, and then there is a layer which arrests its further progress. I cannot, in the nature of things, see why, when we have to use ingot iron or mild steel, it should be supposed that the altered process of manufacture is to produce an entire change in the properties of the material as compared with the best qualities of wrought iron made in the usual way; and I do hope, in spite of Mr. Martell's anticipations, that the result of this discussion will not be to create any fear with regard to the use of steel.

Mr. Martell. I would beg to correct that impression. I should not like it to go abroad that I anticipate any fear whatever, because I do not. My remark was with regard to the impression that was likely to be caused by the remarks made by other speakers, not my remarks. I have myself implicit confidence in steel.

Mr. W. H. White. I think I was very careful to express, not that it was Mr. Martell's opinion, but that it was his fear——

Mr. Martell. I have no fear.

Mr. W. H. White. That the discussion would have that tendency. I am expressing the feeling of all the officers of the admiralty who have had to do with steel when I say it is a more trustworthy material than iron, even of the best quality, which we are accustomed to use.

The President. I will just point out to the meeting that I am, with regard to this paper, deprived of the use of my right arm, because I have not the power of calling for a reply, and, therefore, I must trust to the mercy of the meeting not to protract the discussion to too great a length, bearing in mind that we have two more papers to be read.

Mr. Manuel. My lord, I have listened to Dr. Siemens's explanation with regard to the behavior of the material called mild steel. As his statement affects the use of mild steel, I think it is rather a serious one, because in practice we cannot get rid of these little cracks, or little indentations by chisels, or whatever it is. It is impossible to keep in the working of these plates into boilers or ships perfect freedom from any indentation by the chisel or otherwise. If it is the case that steel, when manufactured into boilers or ships, is liable to break, through the indentation caused by a tool or chisel, it is rather a serious affair. I rather believe in Mr. Thornycroft's reason, which, I think, is much more explanatory. For instance, Dr. Siemens states that good steel would not behave in this way; at least it would not tear but by indentation or notching. I have had a little experience in the testing of steel, and what I have found is that good steel will tear after being punched in such a way as you see here in Fig. 1, and I believe it has been caused by the act of punching or shearing, and without any abrasion whatever; because, after those specimens of steel had been annealed, there was no loss of strength, which you would naturally have supposed would have occurred if abrasion or slight edge tear was caused by the act of punching. Had it been an abrasion caused by punching or otherwise, it would not have been restored to near its original strength by the act of annealing. I will try to explain to you the cause, although I think Mr. Thornycroft has partly explained it. It is this: If you take a steel plate and punch a hole in it—a plate such as this—the effect of the punching causes a hardness or hard ring to form round the edge of the hole at A. When you submit this to a strain—whether it is caused by a machine in the act of testing, or by temperature, as has been explained before, or whether it is at the edge of the plate, as shown in Fig. 1, that this hardness has been caused, or around the hole, the effect is the same, that when you put the strain on your plate the edge of the hole at A is harder than the outside of the plate at B; and, of course, if the outside of the plate gives or stretches, the whole of the strain comes on the thin hard inner ring A, and causes it to give way, simply because the inner ring is harder than the outer part B. I think if plates are damaged by chipping or anything of that sort it is rather a serious thing. I must congratulate Dr. Siemens on the very fine material which he has been able to produce, and, unless in very severe circumstances, I must say it has stood, in my experience, better than any other steels. With regard to Mr. Martell's statement that he would condemn any plates that were found to be cracked, I would say this: the difficulty with regard to it is that, supposing you have a ship nearly finished, and it turns out that there are a few plates showing these mysterious cracks in the act of fitting, it would be rather a serious thing to condemn the whole ship. The plates previously had been tested by Lloyds', I suppose, in the case Mr. Mar-

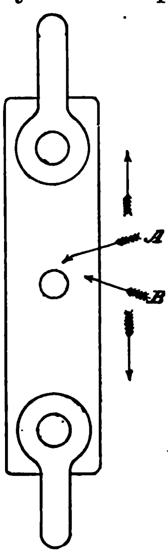


FIG. 1.

tell mentioned, to the entire satisfaction of Lloyds' surveyors, and yet, after all, in the course of the building of that ship, when it was about finished, these cracks turned up in a few plates; and to make a sweeping assertion that it is bad steel, and you must condemn the whole ship for it, is a very serious thing indeed. I must say that Mr. Thornycroft's explanation is quite in keeping with what I should think was the case.

The PRESIDENT. We have two more papers to read to-night. I do not want, against the wish of the meeting, to say a word, and I would not unduly check the discussion of this paper; but it has now lasted for a considerable length of time. If you are very anxious to go on, you must do so, but I would merely state that there are two more papers before us, and it is now half past nine. I think, on the whole, we had better close it.

ON THE QUALITY OF MATERIALS USED IN SHIPBUILDING.

By H. H. West, Esq., *Chief Surveyor, Underwriters' Registry for Iron Vessels; Member of Council.*

[Read at the twenty-third session of the Institution of Naval Architects, 31st March, 1882; the Right Hon. the Earl of Ravensworth, president, in the chair.]

The importance which was attached to quality of materials in the days of wood shipbuilding is abundantly evidenced by the elaborate and valuable rules and tables published at an early date by Lloyds' Register.

Not only was the importance of quality recognized, but the cutting and dressing of each piece of timber to fit it for its place in the ship afforded special facility for ascertaining its constitutional soundness; and the length of time wooden vessels were on the stocks in the process of building permitted a leisurely inspection of every part.

In the present day, however, timber has ceased to be used in any important degree, and the wooden walls of old England have been supplanted by ships of iron and steel. It is to these materials that I purpose directing attention in this short paper.

Designers of structures of all kinds have, perhaps, been too prone to look upon what is popularly known as malleable iron, as a material of definite and invariable qualities, most prominent amongst which were ductility and the power of resisting a mean tensile strain of about 20 tons per square inch. This very broad and general definition of the characteristics of this material was, of course, never seriously formulated in these terms, but its existence as a sort of tacitly-accepted postulate of engineering has undoubtedly had an influence on the quality of ordinary plates and bars, by encouraging an unwarranted confidence in all materials manufactured into these forms.

In the earliest days of the art of iron shipbuilding, the materials were second to none which the country then produced, and those whose duties or avocations have made them acquainted with the iron then used, and that which is now frequently used, will admit that, notwithstanding all the improvements in iron-making, the difference is not creditable to us as the producing country of the world.

When iron shipbuilding became the important industry which the many advantages of the new constructive material made it, a special department of iron-making came into existence, for which a new name was coined—the manufacture of "boat plates."

In the course of time, pressure on shipbuilders for low prices reacted on iron makers, and "boat plates" became a synonym for iron of a low quality; and at a comparatively early period in the history of iron shipbuilding, no less an authority than the late Sir William Fairbairn, after the fatal wreck of the Royal Charter, spoke in scathing terms of the badness of this class of iron. He said in a letter to the Times: "If I may be permitted the paradox, iron is not always iron. It is sometimes rubbish; and in this category I would unhesitatingly place all 'boat plates.' * * * It is their *inequality* and *uncertainty* which is most to be dreaded. The strength of the whole is that of the weakest part; and when I tell you that out of the same 'boat plate,' or iron of that quality, two pieces have been taken, one of which sustained twenty-two tons to the square inch of section while the other failed at five tons. I have said enough to show why this dangerous material should be at once discarded in building ships. * * * Boat plates are shams. They are got up to deceive by appearances. Smooth and well-looking on the surface, the source of mischief lies hidden underneath." And again, in another letter to the same newspaper, under date of October 31, 1858, he made use of these emphatic words: "Built of the 'boat plates' of the present day; God help the human freight of the ship that strikes upon a rocky shore."

After this vehement denunciation, and possibly in consequence of it, little was heard for some time of inferior materials being used by iron shipbuilders, but the exigencies of low-priced contracts eventually brought about their inevitable consequence—the occasional, if not the frequent, use of iron of a comparatively low character.

I am far from saying that our shipbuilding iron is universally bad, but from investigations which it has occasionally been my duty to make, I have found that the quality of iron delivered to our shipbuilders is by no means universally equal to the standard of the broad definition to which I have referred.

I need hardly say that the expense and delay which a shipbuilder must incur by exception being taken to material after its delivery at his yard is very serious. But the duty of rejecting any insufficient materials is one that surveyors, to their credit be it said, have not hesitated to face when they have found indications of inferior materials being used. At the same time the very conscientiousness which makes a surveyor undertake this disagreeable duty will make him careful that, before making his complaint, he has good grounds on which to base it.

This leads to the remark that the process of working the iron into the ship does not necessarily reveal its defects.

The greater part of the plates of an iron ship have but little curvature, and the ordinary processes of preparation afford but a very slight test of quality. The plates which are shaped to any considerable degree are usually ordered of special quality of iron, and, being furnaced, are not likely, in ordinary cases, to show failure. Again, the speed with which iron vessels are now constructed, leaves only a short time between the iron leaving the maker's works and its being riveted up in the ship of which it forms part, so that even skilled and careful inspectors may sometimes fail to detect faulty material.

Surveyors, then, are at a disadvantage in examining into the quality of materials used in the construction of iron vessels as compared with their forefathers who surveyed the wooden ships of years gone by; and there is some excuse for them if the course of their survey occasionally leaves them in ignorance of the character of some of the material which has been put into the structure for the sufficiency of which they have accepted a responsibility.

Now, what is the position of the shipbuilder in this matter? He is usually in the hands of the iron maker. In bad times he must buy on the lowest possible terms, or he will not make both ends meet in his contract with the shipowner. In good times the demand on manufacturers is so great that the builder is only too glad to get iron of any kind. Moreover, he has ordinarily no special contract with the manufacturer as to quality. He has merely ordered so many tons of certain specified sizes of shipbuilding iron at a certain contract price. Generally no tests are specified, and, unless embodied in the contract, they would certainly be declined. The natural contention of an ironmaker would be that a good and sufficient quality had been delivered, if with ordinary skill and care the iron was capable of being worked into the ship without failure in the process of working. But, as I have already shown, this is a test of very little real value in showing the quality of the material.

For manifest reasons I cannot quote the names and details of particular cases, but some of the facts which have come under my official cognizance are such as make it a duty to call attention to the deterioration in this matter into which we are running the risk of sinking. Iron has been, and not infrequently is, delivered for shipbuilding purposes which would certainly not pass the admiralty regulation tests for ordinary B iron. These tests are indicated in the following table, which shows the angles to which the various thicknesses must bend cold without fracture, and the tensile resistance required with and across the grain of the iron. It will readily be admitted that these tests are far from onerous.

Admiralty tests for B or second-class iron.

Lengthway series (tensile strain 20 tons per square inch).			Crossway series (tensile strain 17 tons per square inch).		
Thickness.		Angles in degrees.	Thickness.		Angles in degrees.
Sixteenths.	Decimals.		Sixteenths.	Decimals.	
16 & 15	1.0 & .94	10°	16 & 15	1.0 & .94	—
14 & 13	.88 & .81	15°	14 & 13	.88 & .81	—
12	.75	17½°	12	.75	5°
11	.69	20°	11	.69	5°
10	.63	22½°	10	.63	7½°
9	.56	25°	9	.56	7½°
8	.5	30°	8	.5	10°
7	.44	37½°	7	.44	12½°
6	.38	45°	6	.38	15°
5	.31	55°	5	.31	17°

During the last few days I have had samples of iron taken without any selection from shipyards in all parts of the country, and the fractures of these can be inspected by those interested as the samples lie on the table. Perhaps I should add that they have purposely been so mixed up as to defy identification even by myself, and therefore they may be discussed with perfect freedom.

It is clear that the scantlings required by the rules of the classification societies must be based, not on the maximum quality, but on the minimum, or, at least, on the average quality in ordinary use, so that, in consequence of the comparatively low quality of some of the iron used in ship construction, an increased quantity has to be demanded, and thus the practical outcome of all this is a tax—a permanent tax—on the whole civilized community, the full extent of which it is almost impossible to estimate.

Although a certain standard quality of iron is required by the rules of the classification societies, systematic tests of quality have only been resorted to in cases where the material has given indication of defect; indeed, universal and stringent testing never became one of the conditions of classification until the introduction in recent years of steel as a shipbuilding material.

The exceptionally good qualities claimed for steel and its high price demanded that, if its good qualities could be established, a reduction of scantlings should be conceded. It was necessary, then, in order that this concession should be granted, that the quality should be beyond suspicion. Hence the elaborate and stringent tests which have been required for steel, and which have had so beneficial an effect in maintaining the high standard with which this material commenced its career.

It would probably be impracticable, on account of the immense quantities to be dealt with, to submit shipbuilding iron to the same official tests which steel now undergoes; but I would urge upon iron-makers in their own interest to pass all their material through systematic tests of their own before issuing it to constructors.

The increased and increasing demand for steel will assuredly cheapen it, and it will only require a very moderate reduction in the price to insure that all ship-owners who value the satisfaction of having everything of the best will make it a *sine qua non* that their ships shall be built of steel, unless iron again establishes itself as a material which may be relied upon for uniformly good qualities.

DISCUSSION.

Mr. BENJAMIN MARTELL. My lord, the object of writing this paper, I apprehend, is contained in the last paragraph; that is, an advice to iron-manufacturers to produce a better quality of material, which I cordially approve. Now, I suppose that the specimens we see here are specimens of iron being used in ships that are building under Mr. West's supervision.

Mr. WEST. And Mr. Martell's.

Mr. MARTELL. I should suppose it is not customary, and I should feel very great delicacy in going into any yard and selecting any material that was to be used in building a ship for classification in any other register society than that to which I belong. All I can say is, that the specimens that are brought here are specimens of very inferior material. I cannot tell where they have been obtained, but it is evident that many of them are very inferior material, and I can only say that there would be no difficulty in any surveyor understanding at once that it was a very inferior material, perfectly unfit for shipbuilding purposes, and it would be his duty to condemn it; and if he did not, the surveyor would not be doing his duty, and would not be fit to belong to a classification society. Now, some time ago there had been a great deal of talk about the inferior iron used in ships, and I went round all the shipyards at the principal ports, at the instigation of the committee of the society I have the honor to serve. I went into those yards (I did not tell the builders I was coming), and I collected material in every yard, and subjected that material to different tests, cold and hot bending tests, and those specimens were all sent up to our committee for inspection. They were taken indiscriminately, and all I can say is that the collection of iron was very different from what we see in that box; and I was further much surprised to find, taking the samples throughout, the generally satisfactory quality of the iron that was being used throughout the country. It did not bear out at all the assertion made that iron used for shipbuilding was "rubbish—was not iron, or anything of the kind." Of course, what gave rise to the quotation from Sir William Fairbairn happened a good many years ago; and how is it if the iron was so very much superior, as some assert at that time, that the iron in that ship was found to be such as described? If it has deteriorated from that time, as some say, it would be at the present time veritable rubbish, not iron at all, and such as Mr. West would lead us to believe. We all know that iron is not of the same uniform quality as mild steel, and not to be compared with it as to ductility—we understand that perfectly well; but I do not accept those specimens at all as fair specimens of the material that is being used in the construction of the 1,200,000 tons of ships that we have building at the present time throughout the country under the inspection of the surveyors of the society I belong to. It is not anything like the general quality of iron that is being used in those ships, and although I am quite as desirous as Mr. West of improving the quality of iron for shipbuilding purposes, I should not like it to go abroad throughout the country that we are using such miserable rubbish as the specimens here before us would seem to show.

Mr. J. D'A. Samuda. My lord, I do not profess to come to the exact conclusion that Mr. Martell did in starting as to what the intentions were with which this paper had been written, but I must think that as far as drawing our attention to a most material point, and to material differences in qualities which have existed since shipbuilding has been introduced in that which has generally been made use of as iron for shipbuilding and for different purposes, I think it is an extremely valuable paper, and I think we should do well to address ourselves, first, to ascertaining what the causes of the inferior quality may be in some respects due to, or in most respects due to, and next to ascertaining what steps are being taken to correct so great an error as this falling into the very low character of iron which shipbuilding has been represented in this paper to have descended to. Now, first, before I go into the question of iron, I should like very much to say this, because I think this is a very important point for us to start from, and might be useful to those to whom I am referring in their mode of dealing hereafter with their iron ships. Lloyds' have a great influence in this country by giving to shipbuilders a certificate, as it were, of safety, which they are content to rely upon, and shut their eyes to everything behind that certificate—that is to say, that many shipbuilders, relying upon the character of a ship which takes the highest classification at Lloyds', can apply for freights with the full assurance that they will be received with open arms, and their ships given a preference over those ships plying in competition with theirs without any such classification at their back. Lloyds', in dealing with steel, have taken what everybody must be satisfied is a very satisfactory course. They have adopted a most careful supervision at the works of the steel that is being made, to ascertain that to the best of their ability they get the best quality, they have by local inspectors taken upon themselves the duty of testing every single plate, and a reliance is consequently obtained on the material that is put in the ship, and I do not hesitate to say that, as a general rule, that which is put in the ship is, in consequence, as good as it can be obtained. Have they done anything of the sort with iron? Nothing of the sort.

Mr. MARTELL. I beg your pardon.

Mr. SAMUDA. If you will allow me I will now go back to times before Mr. Martell was connected with the association—I am going back to the period when Lloyds' began to build iron ships. What was the course they took? The course they took was this. They applied to myself and others to give them such information of what we were doing as enabled them to base a table of general strengths, upon which their scantlings should be framed. I do not hesitate to use names. The men with whom I was brought in direct contact, and who were then in a similar position to that which Mr. Martell holds at the present moment, were Mr. Martin and Mr. Ritchie. In this way I gave them freely, and other people did the same, the whole of the information that we had at our disposal, and they framed their tables. About twelve months after that they brought out new tables, and these tables had all the scantlings enormously increased. I said to them: "What is the reason that you have made this vast change? You put into a vessel of 500 tons something like 100 tons additional weight; you have taken away from the advantage of this ship, and in what way have you ever found these ships, of which we have given you and you have adopted the scantlings, fail, and show insufficiency of strength?" They said, "No, we have not found it, but we have not to deal only with iron of this quality; we have to deal with iron that is put into ships throughout the whole of the Kingdom, and that which is put in generally is of a totally different quality—very inferior; and therefore we have thought it necessary to increase the quantity of weight, to make up for the deficiency of quality." I think you will immediately see that at least one paragraph in this paper will be found by you to be perfectly correct; at any rate, I will put it to you in that way. Therefore, for the purpose of obtaining a security against the very worst material, those who gave the very best had to pay the penalty of putting in a very considerable additional quantity of work, or be shut out from competition generally. That is exactly what has taken place. I pressed it upon them, and I said, "Do not do anything of this sort. Satisfy yourselves. Get rid of this unfortunate quality that has been created for the purpose of building ships." A general impression has existed that because ships are not subjected to exactly the same strains that boilers are and cannot be measured in the same way, that therefore any rubbish will do for ships, and this observation of Sir William Fairbairn's does fairly represent the difference between what are called "ship plates" and what are called "boiler plates." I have again and again in this room, among other places, pointed out that I never allowed anything short of a boiler plate to come into my yard—I never used ship-plates, but ship-plates are used universally. We heard last night of steel playing what were called "mysterious antics." I do not wish to go back to that controversy, I did not agree with it; but I will tell you some mysterious antics I have seen ship-plates play. I am going back now about twenty years. I had a ship sent to my place to be repaired which had the highest certificate that Lloyds' could give. This ship laid upon the hard, about twenty yards down from the wharf, and an empty barge slid down from the wharf, touched against this ship, knocked a hole in it, and broke four plates as if they had been four pieces of glass. That ship had got the highest certificate from Lloyds'. It is perfectly clear that Lloyds' had taken no means whatever to ascertain the quality of this material. But they never did take that. I urged upon them over and over again at the period I am now referring to, and at one time I think and believe they did for a short period enter in their rules something with reference to their making it a necessity that iron should possess a certain strength, not the same as that which the admiralty rule required, but something approaching it, but, however, they wiped it out again, and said that they found it too difficult, because the opposition of builders generally was too great for them to continue it.

Mr. MARTELL. I beg your pardon; it is in the rules at the present time.

Mr. SAMUDA. I am glad to be corrected, but I am informed most distinctly that it is not.

Mr. MARTELL. The rule is that it must stand a test of 20 tons with the grain and 18 tons against, and be of good malleable quality.

Mr. SAMUDA. I am perfectly ready to accept any correction, Mr. Martell, but I will ask at what period of time that was introduced into the rules?

Mr. MARTELL. It is now some years since.

Mr. SAMUDA. It is difficult for me to contradict that, but, at any rate, I can speak most positively that for an immense number of years it was not there.

Mr. MARTELL. I do not know that.

Mr. SAMUDA. But even if it has been introduced into rules without such other means or care as should have secured for them the getting the best iron in the same way that they now seek and do succeed in getting the best steel, I want to point out to this committee how exceedingly dangerous it is to trust to any great industry like shipbuilding, when it has to hang its success or otherwise upon so delicate a matter as being able to give to the public an assurance of sufficiency and of success by a constituted authority, unless that constituted authority can be in all respects equal in experience to those who are manufacturing the article that they are supervising. There, I think, Lloyd's have entirely failed; they have evidently in some shape or another failed, or they never would have allowed iron to degenerate in the way in which it has degenerated, and is described in this paper to have degenerated and properly described, below that which has been used for boilers for all previous years. Now, I do not it think it is necessary to go very much further into that matter than I have done. I only hope that in future the success which Lloyds' have found, and must find they are obtaining by the course they are adopting with steel, will be followed out by them, and that they will try equally to obtain a suitable and similar measure of iron, and that they will begin by forbidding altogether that half-manufactured stuff which is called ship-plates to be used at all.

Mr. Raylton Dixon. My lord, as a shipbuilder I am sure I cannot accept the statement made by Mr. Samuda as to the great degeneration of shipbuilding iron during the last twenty or twenty-five years, and I must say that the samples we see here before us, which Mr. West has produced, seem to me as if they had been taken (I do not know whether Mr. West was quite clear upon that point or whether I understood him) from plates condemned by his surveyors in different parts, and not plates ordinarily used. I would appeal to any gentlemen who are shipbuilders, and who use these materials, whether it be Cleveland iron, or Scotch, or any other, as to whether plates like these are such as are in ordinary use. With regard to what Mr. Samuda said, that he adopts nothing but boiler-plates in the construction of his shipping, I am sure, for my own part, that I and every other shipbuilder would be glad to do the same if we had the opportunity, but I think if I had ever to compete with Mr. Samuda for the building of a commercial steamer, I should feel that I was pretty safe in putting a very considerable margin on, because it would be impossible to compete with other builders and use that high quality of iron. It rests not so much with the shipbuilder as with the ship-owner, and with the authorities of Lloyds' and the Liverpool underwriters, as Mr. Samuda has very aptly said, to decide upon the strength of the material that we shall use. I think that rather too much stress has been laid upon the quality of it, and that an unfair aspersion has been cast upon the general builders of vessels by suggesting the use of material so utterly unfit for it as several of the pieces of iron which I see before me there. If we go to the statement of Sir William Fairbairn mentioned here, "God help the human freight of the ship that strikes upon a rocky shore!" I can only say, whatever the material, if it comes to that, God help it, because under those circumstances the question of a little difference in the quality of iron would not be at all material. I certainly do feel, with regard to the question of steel and iron, that perhaps there is a little unfair treatment there between the two, because if anything happens to a steel plate, an accident or breakage, it becomes almost historical, whereas iron is allowed to pass through the inspection much more freely; but we do not, as has been stated, in ordering iron for shipbuilding purposes, give our orders for that material without stipulating the quality that it shall be. I think in every case where iron is ordered for shipbuilding it is ordered to stand the test required by Lloyds', which is 20 tons and 18 tons, and I believe we generally get it. I really think that Mr. West has introduced a rather unnecessary scare by the exhibition of these pieces of material, and I would certainly protest that it is not fair to consider them as the material which is being ordinarily used in the present day for shipbuilding purposes.

Mr. JOHNSON. My lord, if we accept the axiom that the strength of the whole is that of the weakest part, it seems to me that the samples shown by Mr. West must be taken as a standard, because it is as likely as not that a plate similar to the samples shown would get in a portion of the structure likely to be severely strained. In such a case the inevitable result would be that the plate in question would give way; an undue strain would thereby be thrown on the remaining portions, and the whole structure would be seriously endangered. I should like to ask Mr. Martell how often they subject iron to the test which he mentions of 18 tons and 20 tons.

Mr. JOHN. My lord, I will only say a word or two. I entirely indorse what Mr. Martell and Mr. Dixon have said about the general quality of iron used throughout the country. I know Mr. Martell when I was at Lloyds' had an opportunity of testing iron throughout the country, and we were rather astonished than otherwise to find it so invariably good. I go further, my lord, in reference to what Mr. Samuda says, I say the difference of cost between the quality of ship plates as used—I am speaking generally, I do not mean bad samples but the general quality of ship plates which are capable of standing 20 tons with the grain and 18 tons against the grain, and the boiler plates which Mr. Samuda talks about using capable of standing 22 tons one way and 20 tons the other—is far more than the difference in the quality of the material warrants, and it would be a waste of public money to build the whole of the mercantile marine of this country of boiler-plates for the sake of the other two tons to the square inch. There is one little illustration I will give you as to the quality of iron. We are building some ships at the present time where we have a clause in the specification which requires certain tests. We asked for quotations, and we got quotations for ordinary ship-plate iron. I had to draw the attention of the makers to the fact that there was this clause, and that this iron would have to stand not only all the tests put down there, but, further, the tests for elongation with the grain and elongation against the grain; and I assure you there was only a slight difference of price put on; I believe we got exactly the same iron, and the price was not two shillings a ton more—it was simply put on to cover any little bother they might have in testing. That is an illustration of the fact of what the general quality of the iron is capable, and makers are not much afraid, and put on very little to the price, if they have to make tests of that kind. It is a common thing in buying iron to say, is it to stand Lloyds' tests? That is, are you to be in a position to reject it if it will not stand 20 tons one way and 18 tons the other; and all the iron in the country is sold to shipbuilders under conditions of that kind.

Mr. PHILLIPS. My lord, I was rather surprised to find the aspersion on the quality of iron in Mr. West's paper. In my experience the quality of iron daily coming under my observation is far better than it was some years since. I remember about five years ago in the course of my official duties having had occasion to reject a large quantity of material for mast-plates and ship-plates, and since that time I have found that the quality of iron has been everything that can be desired. I rise to say that only two days since in testing some mast-plates I found that $\frac{3}{8}$ iron with the grain stood as much as 87° and across the grain 34°, which I think is considerably in excess of what is represented in Mr. West's paper. I think it is only the duty of those people who know of and meet good qualities of iron to stand up and by every means in their power prevent aspersions being made upon the quality of iron manufactured at the present time.

Mr. W. W. RUNDELL. My lord, it seems to have been taken as a matter that need not be argued that these plates before you would all fail to stand the 20-ton test with, and the 18-ton test across the grain. That is entirely an assumption; whether it is a correct one or not I leave it to the meeting to judge. For my own part, I cannot pretend to a practical acquaintance with these matters, but I fancy I could pick out specimens from among them that would possibly stand that test easily, but yet they have all been rejected wholesale, not because they would not stand the usual tensile test, but because they were unfit, as these practical men say, for use. It must not be, I think, so readily assented to, that all the specimens of iron now exhibited would not stand the tensile test.

Mr. WITHY. My lord, I should like to confirm what Mr. Rundell has said. No doubt a great deal of the hardest iron used in shipbuilding would stand this tensile strain, and stand it very well, but we want also malleability. I am quite prepared to believe, though I have not looked closely at these specimens, that there is some iron used in shipbuilding which is very bad, and possibly as bad as those specimens; but I quite agree with Mr. Dixon and with those gentlemen who assert here that that is not at all the usual class of iron in shipbuilding. I think we may revert to Mr. Glover's statement yesterday, that the probability is that at least 95 per cent. of the shipowners and shipbuilders are respectable people. I will go as far with Mr. West as to say that I think it would be a very valuable thing if Lloyds' did introduce tests at the works for plates and angles. It is scarcely fair to put steel at such a disadvantage as it is now put by testing it so severely, when iron is left to go free, because I make bold to say that, although Mr. Martell is quite right in saying the testing clause does occur in their rules, it is practically a dead letter. While saying that, I would, however, indorse what Mr. John says, that it is probable the great bulk of iron used in shipbuilding at the present day would stand it, and I do not think the difference of price would be worth paying for boiler-plates. We have not the expansion and contraction under heating and cooling in ship practice, nor many of the things that are required in boilers. Lloyds' have recently commenced testing forgings at makers' works, and I think that is a very valuable thing to do. I should like myself to see them carry it further, and test iron plates at the works. I believe, beyond the paltry shilling or two to which Mr. John alluded, that would be the only additional expense entailed on shipbuilders, and there certainly would be some satisfaction in it. Cases like that which Mr. Samuda has mentioned, of barges or large structures running into iron vessels and making holes in them, are quite correct. I have known a case in launching a steamer where the supports to the ways at her ends, past where the close packing went to, and where upright posts of something like twelve inches square of memel were fitted, that one of those pieces, coming between the frames, positively went through the vessel when she took an awkward dip. I believe, however, that that sort of thing is quite unprecedented. Mr. West has done good service in calling attention to the matter, possibly in an exaggerated form, but it will not be without its fruits if it leads to more attention being given to the malleability of shipbuilding iron

Mr. H. H. West. My lord, first, in reference to the samples on the table, I beg to say that they have been taken promiscuously, without any selection for badness or for goodness—they were taken just as they happened to come. The plates were not necessarily condemned because of those crystalline fractures; but they must necessarily have been condemned as respects their original purpose, because the corner of the plate had been taken off. The condemnation of iron of that quality, at least showing a fracture of that kind, should not in my judgment rest simply upon the fracture. If any one examines these samples he will see some that are very crystalline in appearance, and yet have manifestly bent to a considerable angle before they have broken, showing an amount of malleability that you would not expect from the nature of the fracture. And further, as Mr. Rundell pointed out, they might very well stand the tensile tests required by Lloyds' rules and our own rules. Mr. Martell is right in what he says, that Lloyds' rules, as well as ours, do provide for a certain quality of iron, and I believe the words are very much the same in both rules; but as a matter of fact—and Mr. Martell I am sure will uphold me in what I say—that iron is only tested when a question arises; it is not until certain circumstances come about that the rule is put strictly in force. In reference to what Mr. Martell said about these being Liverpool ships and not Lloyds' ships, I think that may pass without further comment. Mr. Samuda put the question as a matter of two principal aspects: first, whether the statement is correct that iron has deteriorated; and secondly, what is being done to remedy